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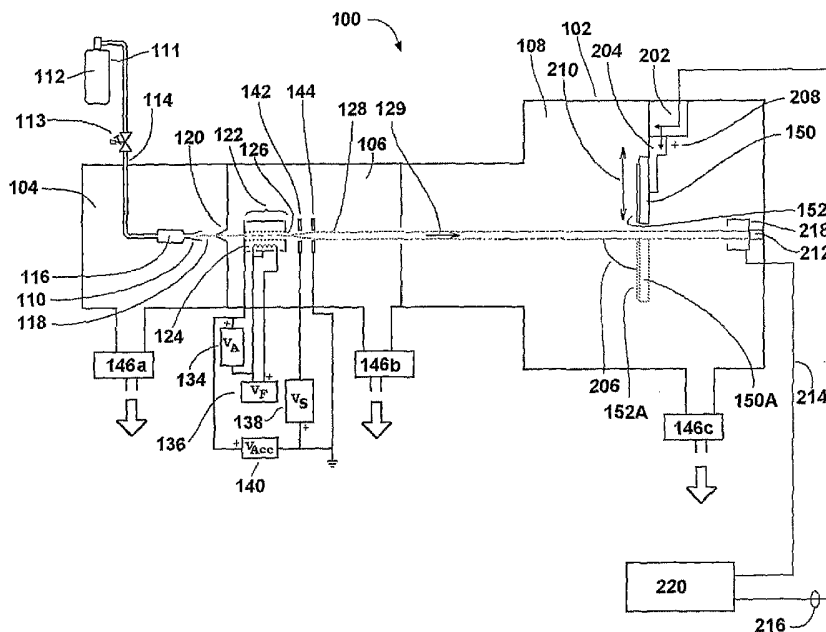
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(54) Title: METHOD AND APPARATUS FOR ARC SUPPRESSION IN SCANNED ION BEAM PROCESSING EQUIPMENT



(57) Abstract: In an ion beam acceleration system, transient electrical arc suppression and ion beam accelerator biasing circuitry. Two-terminal circuitry, connectable in series, for suppressing arcs by automatically sensing arc conditions and switch from at least a first operating state providing a relatively low resistance electrical pathway for current between source and load terminals to at least a second, relatively high resistance electrical pathway. Selection of circuit component characteristics permits controlling the delay in returning from the second state to the first state after the arc has been suppressed.

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METHOD AND APPARATUS FOR ARC SUPPRESSION IN SCANNED ION BEAM PROCESSING EQUIPMENT

Field of the Invention

5 This invention relates generally to methods and apparatus for suppressing undesirable processing effects caused by spurious arcing in scanned ion beam processing equipment. More specifically, the invention relates to reducing non-uniform processing and increasing equipment reliability in scanned ion beam processing equipment.

Background of the Invention

10 The use of a scanned gas-cluster ion beam (GCIB) processing a surface of a workpiece, for etching, cleaning, and smoothing surfaces is becoming a well-established industrial process. Scanned ion beams are also used in the field of ion implantation where conventional

15 monomer ion beams are used rather than GCIBs. In most equipment that uses scanned ion beams to uniformly process a surface of a workpiece, there is a problem that results when undesired arcs occur at high voltage points in the equipment. In most circumstances, the occurrence of a high voltage arc in an ion-beam processing tool results in a momentary interruption of the ion beam. In a beam-scanning or workpiece-scanning system, by the time
20 the arc has been extinguished, scanning has often moved the ion beam relative to the workpiece so that normal processing resumes at a different position on the workpiece than where it was terminated by the arc. The normal result is that a portion of the workpiece is not uniformly processed, and this often results in a reduced product yield in the ion beam processing equipment.

25 A high voltage power supply normally has a stored energy that can be discharged rapidly by an undesired arc, but which may not be rapidly recovered. Also, regulation circuits may not respond quickly when an arc discharges a high voltage power supply. For these and for other

reasons, it is often the case that when a high voltage power supply is discharged by and undesired arc, normal operating voltage may not be restored for a period of tens or even hundreds of milliseconds (msec.) In high throughput processing equipment like an ion implanter or a GCIB processor, such a lengthy recovery time results in non-uniformity of the process.

Another problem arises when an undesired arc rapidly discharges the high stored energy of a high voltage power supply, Electromagnetic Interference (EMI) transients can disrupt the operation of control systems, or even destroy sensitive components in nearby electronic circuits. For this reason it is highly desirable, in the event of an unintended high-voltage arc, that the arc be interrupted before the entire stored energy of the high voltage power supply is dumped.

Accordingly, it is an objective of the present invention to provide a fast responding means to terminate an unintended arc so that normal processing can be rapidly restored.

A further objective of the invention is to provide an electrically floating apparatus for terminating an unintended high voltage arc at a high voltage terminal without need of a separate power source nor any other connection to the ground terminal of a high voltage power source.

Another objective of the present invention is to provide a means to terminate an intended high voltage arc without permitting the complete discharge of stored energy in the high voltage power source.

Summary of the Invention

The objects set forth above as well as further and other objects and advantages of the present invention are achieved by the embodiments of the invention described hereinbelow.

The present invention provides a self-biasing, self triggering and self-resetting circuit that rapidly extinguishes a high voltage arc by interrupting the arc current prior to complete discharge of the stored energy in the high voltage source. This reduces EMI effects and results in much more rapid recovery of normal processing by a workpiece processing system that uses an ion beam generated by a means dependent on a high voltage power source (an ion beam accelerator, for example).

Brief Description of the Figures

For a better understanding of the present invention, together with other and further objects thereof, reference is made to the accompanying drawing and detailed description, wherein:

Figure 1 is a schematic showing the basic elements of a prior art GCIB processing apparatus **100**;

Figure 2 is a schematic of a prior art GCIB processing apparatus **250** with improvements to reduce the adverse effects of high voltage arcing;

Figure 3 is a schematic diagram of an improved arc suppressor circuit **500**;

Figure 4 is a detail of a winding sense of a transformer T1 in accordance with an embodiment of the invention;

Figure 5 is a schematic showing a circuit **620** comprised of a series connection of three two stage circuits such as, for example, the circuit **500** shown in **Figure 3**;

Figure 6 is a schematic showing a circuit **640** comprised of a series connection of three circuits such as, for example, the circuit **620** shown in schematic **Figure 5**;

Figure 7 is a schematic showing an exemplary 30 kilovolt (kV) high voltage power supply **662** driving a load **664** through an arc suppressor according to the invention;

Figure 8 shows a schematic of a GCIB processing apparatus **700** including improvements according to the invention for reducing the adverse effects of high voltage arcing;

Figure 9 is a graph showing voltage and current transients measured in a GCIB processing system without an arc suppressor in accordance with an embodiment of the present invention,
5 acquired at the output of acceleration power supply during an arc transient; and

Figure 10 is a graph showing voltage and current transients measured in GCIB processing system with an arc suppressor in accordance with an embodiment of the invention.

Detailed Description of Certain Embodiments of the Invention

10 **Figure 1** shows a schematic of the basic elements of a typical configuration for a GCIB processing apparatus **100** of a form known in prior art, and which may be described as follows: a vacuum vessel **102** is divided into three communicating chambers, a source chamber **104**, an ionization/acceleration chamber **106**, and a processing chamber **108**. The
15 three chambers are evacuated to suitable operating pressures by vacuum pumping systems **146a**, **146b**, and **146c**, respectively. A condensable source gas **112** (for example argon or O₂) stored in a gas storage cylinder **111** is admitted under pressure through gas metering valve **113** and gas feed tube **114** into stagnation chamber **116** and is ejected into the substantially lower pressure vacuum through a properly shaped nozzle **110**. A supersonic gas jet **118**
20 results. Cooling, which results from the expansion in the jet, causes a portion of the gas jet **118** to condense into clusters, each consisting of from several to several thousand weakly bound atoms or molecules. A gas skimmer aperture **120** partially separates the gas molecules that have not condensed into a cluster jet from the cluster jet so as to minimize pressure in the downstream regions where such higher pressures would be detrimental (e.g., ionizer **122**,
25 suppressor electrode **142**, and processing chamber **108**). Suitable condensable source gases **112** include, but are not necessarily limited to argon, nitrogen, carbon dioxide, oxygen, and other gases and/or gas mixtures.

After the supersonic gas jet **118** containing gas-clusters has been formed, the clusters are ionized in an ionizer **122**. The ionizer **122** is typically an electron impact ionizer that produces thermoelectrons from one or more incandescent filaments **124** and accelerates and directs the electrons, causing them to collide with the gas-clusters in the gas jet **118** where the jet passes through the ionizer **122**. The electron impacts with clusters eject electrons from the clusters, causing a portion the clusters to become positively ionized. Some clusters may have more than one electron ejected and may become multiply ionized. Suppressor electrode **142**, and grounded electrode **144** extract the cluster ions from the ionizer exit aperture **126**, accelerate them to a desired energy (typically with acceleration potentials of from several hundred V to several tens of kV), and focuses them to form a GCIB **128**. The axis **129** of the supersonic gas jet **118** containing gas-clusters is substantially the same as the axis of the GCIB **128**. Filament power supply **136** provides filament voltage V_f to heat the ionizer filament **124**. Anode power supply **134** provides anode voltage V_A to accelerate thermoelectrons emitted from filament **124** to cause the thermoelectrons to irradiate the cluster-containing gas jet **118** to produce cluster ions. Suppression power supply **138** provides suppression voltage V_s to bias suppressor electrode **142**. Accelerator power supply **140** provides acceleration voltage V_{Acc} to bias the ionizer **122** with respect to suppressor electrode **142** and grounded electrode **144** so as to result in a total GCIB acceleration potential equal to V_{Acc} . Suppressor electrode **142** serves to extract ions from the ionizer exit aperture **126** of ionizer **122**, to prevent undesired electrons from entering the ionizer **122** from downstream, and to form a focused GCIB **128**.

A workpiece **152**, which may be a semiconductor wafer or other workpiece to be processed by GCIB processing, is held on a workpiece holder **150**, which can be disposed in the path of the GCIB **128**. Since most applications contemplate the processing of large workpieces with spatially uniform results, a scanning system is desirable to uniformly scan a large-area workpiece **152** through the stationary GCIB **128** to produce spatially homogeneous workpiece processing results.

An X-scan actuator **202** provides linear motion of the workpiece holder **150** in the direction of X-scan motion **208** (into and out of the plane of the paper). A Y-scan actuator **204** provides linear motion of the workpiece holder **150** in the direction of Y-scan motion **210**, which is typically orthogonal to the X-scan motion **208**. The combination of X-scanning and Y-scanning motions moves the workpiece **152**, held by the workpiece holder **150** in a raster-like scanning motion through GCIB **128** to cause a uniform (or otherwise programmed) irradiation of a surface of the workpiece **152** by the GCIB **128** for processing of the workpiece **152**. The workpiece holder **150** disposes the workpiece **152** at an angle with respect to the axis of the GCIB **128** so that the GCIB **128** has an angle of beam incidence **206** with respect to a workpiece **152** surface. The angle of beam incidence **206** may be 90 degrees or some other angle, but is typically 90 degrees or near 90 degrees. During Y-scanning, the workpiece **152** and the workpiece holder **150** move from the position shown to the alternate position "A" indicated by the designators **152A** and **150A** respectively. Notice that in moving between the two positions, the workpiece **152** is scanned through the GCIB **128** and in both extreme positions, is moved completely out of the path of the GCIB **128** (over-scanned). Though not shown explicitly in **Figure 1**, similar scanning and over-scan is performed in the (typically) orthogonal X-scan motion **208** direction (in and out of the plane of the paper).

A beam current sensor **218** is disposed beyond the workpiece holder **150** in the path of the GCIB **128** so as to intercept a sample of the GCIB **128** when the workpiece holder **150** is scanned out of the path of the GCIB **128**. The beam current sensor **218** is typically a faraday cup or the like, closed except for a beam-entry opening, and is typically affixed to the wall of the vacuum vessel **102** with an electrically insulating mount **212**.

A controller **220**, which may be a microcomputer based controller, connects to the X-scan actuator **202** and the Y-scan actuator **204** through electrical cable **216** and controls the X-scan actuator **202** and the Y-scan actuator **204** so as to place the workpiece **152** into or out of the GCIB **128** and to scan the workpiece **152** uniformly relative to the GCIB **128** to achieve

desired processing of the workpiece **152** by the GCIB **128**. Controller **220** receives the sampled beam current collected by the beam current sensor **218** by way of lead **214** and thereby monitors the GCIB and controls the GCIB dose received by the workpiece **152** by removing the workpiece **152** from the GCIB **128** when a predetermined desired dose has
5 been delivered.

The ionizer **122** normally operates at a high positive voltage V_{Acc} , which may be as much as several tens of kV. In the event that a high voltage arc occurs from the ionizer **122** to ground or some other structure, due to some momentarily high pressure in the vacuum, or to some
10 contaminated condition of an insulator surface, or for other occasional unfavorable conditions, V_{Acc} is transiently reduced and may require several tens of msec or even a few hundred msec to fully recover. During the transient, the beam focus provided by lens effects that normally from proper bias of electrodes **142** and **144** with respect to the ionizer **122**, may be completely disrupted, resulting in substantial loss of the GCIB **128**. If a workpiece **152** is
15 being processed the scanning motion of the workpiece holder **150** may momentarily continue during loss of the GCIB. When processing resumes, a processing non-uniformity may appear on the workpiece near the point at which the beam was incident just prior to the arc event.

Figure 2 shows a schematic **250** of a GCIB processing apparatus with improvements to
20 reduce the adverse effects of high voltage arcing. An arc suppressor **252** is installed in the high voltage lead between acceleration power supply **140** and the ionizer **122**. During normal operation, arc suppressors attempt to maintain a relatively low impedance connection between an input A and output B of the arc suppressor **252**. The simplest of prior art arc suppressors is a resistor with a low enough resistance that it does not undesirably limit
25 current during normal operation and with a high enough resistance to limit peak currents during an arcing fault so as to prevent physical damage to components. More complex systems use resistors in combination with lossy inductors and even more complex passive circuits are used. Some active circuits are also known in the prior art. Such active circuits often require an additional connection **256** to a ground-connected element **254**. The ground-

connected element may supply power and/or control signals to the active element in the arc suppressor **252**. A series string of field effect transistors (FETs) is disclosed in German patent document DE 3630775C2, Belke, wherein the FETs are in an on-state during normal operation, but when a ground referenced sensor detects an arc event, control signals
5 transmitted from a ground-connected element (as **254**) causes the FETs to switch off, interrupting the arc current and reducing the dumping of the stored energy in the acceleration power supply. The requirement to have a ground-referenced connection **256** is a disadvantage in some situations, in that it is not always possible or convenient to physically locate the arc suppressor **252** in a location where it can have a ground-referenced connection.
10 Also the requirement of a connection **256** from the arc suppressor **252** to components at ground potential can sometimes provide an unwanted pathway for conducting EMI transients into sensitive circuitry.

Figure 3 illustrates an improved arc suppressor circuit **500**. All components may be selected
15 from commercially available off-the-shelf electronic components, except pulse transformer **T1**. Details of the construction of **T1** are given in **Figure 4** hereinafter, and it should be noted that the disclosure of specific winding and/or core characteristics is by no means meant to be limiting. **Q1** and **Q3** comprise insulated gate bipolar transistor (IGBT) devices, preferably type IRG4PH50U, such as supplied by International Rectifier, El Segundo,
20 California, USA. **Q2** and **Q4** comprise standard bipolar transistors, preferably type 2N3904, sourced by multiple manufacturers, worldwide. Transient voltage suppressors **D1**, **D2**, **D3**, and **D4** comprise 600 watt peak power, bi-directional transient voltage suppressors having maximum clamping voltages of from about 10 to about 25 volts at peak pulse currents of about 20 amps or more. Transient voltage suppressors such as these are available from
25 Vishay Semiconductors under the trade name of TRANZORB®, widely distributed by electronic distributors in the United States and described in detail in Vishay Document Number 88369 dated October 9, 2002, the contents of which are incorporated herein by reference. Vishay part types P6KE6.8CA and P6KE15CA are examples of transient voltage suppressors that can be used for **D1**, **D2**, **D3**, and **D4**. Type P6KE15CA is preferable. **VR1**
30 and **VR2** are metal oxide varistors (MOV) type V66LA50A or type V575LA40A

(V575LA40A preferred) sourced by Littelfuse of 800 E. Northwest Highway, Des Plaines, IL 60016 USA. **C2** and **C4** are conventional ceramic capacitors, approximately 0.1 microfarads, with multiple sources. Optional ceramic or film capacitors **C1** and **C3** are preferably included having capacitances of approximately 0.47 microfarads, with multiple sources.

- 5 Resistors **R1**, **R2**, **R3**, **R4**, **R5**, and **R6** preferably comprise low inductance carbon composition or carbon film resistors with multiple sources. **R1** and **R4** have approximately equal values of from about 1 kohm to about 10 kohm, preferably about 1 kohm each. **R2** and **R5** are each approximately 1 Mohm. **R3** and **R6** are each approximately 1 kohm. Optional resistors **R30** and **R31** are preferably not included, but when included are each approximately
- 10 1 megohm. Suppressor circuit **500** has a power source terminal **A** and a load terminal **B**. When used to protect the output of a positive power supply driving a load, the source terminal **A** is connected to the output of the positive power supply and the load terminal **B** is connected to the load. The connections are reversed in the case of a negative power supply driving a load. The load establishes a current, from microamps to milliamps. This current,
- 15 which is predominantly determined by the power supply voltage and the load, passes through **R2**, **D1**, the primary winding (designated **P**) of pulse transformer **T1**, **R5**, and **D3**, and produces voltage drops across **D1** and **D3**, creating an initial gate (**G**) to emitter (**E**) bias voltage at **Q1** and **Q3** which biases the gates of **Q1** and **Q3** IGBT devices positive relative to their emitters, turning the IGBTs **Q1** and **Q3** on. Once these IGBTs are switched on, the load
- 20 current flows almost entirely through **R1**, **Q1** (collector **C** to emitter **E**), **T1** (**P**), **R4** and **Q3**(**C** to **E**). The effective series resistance of the arc suppressor circuit during normal operation is approximately from 1 kohm to 10 kohm, depending upon the values of **R1** and **R4** times the number of stages (two are shown in Fig. 3). These preferably 1 kohm (**R1** and **R4**) resistors then dominate the self-biasing, due to the voltage dropped across them. Upon
- 25 initiation of an arc discharge at or across the load, the current through **R1**, **Q1**, **R4**, **Q3** and **T1**(primary winding **P**) increases. The rapid rise time of this step induces a voltage across (and current through) transformer **T1** (primary winding **P**), which in turn induce rising voltages on the two secondary windings (designated **S1** and **S2**) of pulse transformer **T1**. These rising edge signals, in turn, drive the current through the bases (**B**) of **Q2** and **Q4**
- 30 respectively, on, thereby pulling the gates of **Q1** and **Q3** low, turning the IGBTs off. **C2** and

C4 capacitors ensure rapid transistor turn-on during the rising edge from T1 secondaries S1 and S2 voltage transients. When the IGBTs Q1 and Q3 turn off in response to an arc condition, the arc current must then flow through the much larger resistance pathway of R2, D1, the primary winding (designated P) of pulse transformer T1, R5, and D3. This greatly
5 limits the arc current by increasing the resistance of the circuit by two to three orders of magnitude, depending on the values chosen for R1 and R4, over the normal resistance when Q1 and Q2 are conducting. The dual secondaries S1 and S2 of the transformer T1 assures that both IGBT devices Q1 and Q3 are turned off at the same time. The combination of R2, R5, (C1 and C3, if present), the Q1 and Q3 gate-to-emitter capacitance, and the Q1 and Q3
10 turn-on characteristics produce a short delay, holding Q1 and Q3 off for from about 0.25 to about 4 msec (typically about 1 msec using the preferred components and values), allowing for the arc to extinguish before Q1 and Q3 turn back on. This delay can be adjusted, within limits, by selection of the values and characteristics of the components that contribute to it. D1-D4 protect the gates and bases of the transistors Q1-Q4. Although Q1 and Q3 are
15 IGBTs, it will be readily understood by those skilled in the art that suitable FETs can also be substituted for the IGBT devices with suitable circuit adjustments.

Although pulse transformer T1 is used, it will be readily understood by those skilled in the art that optical-isolators can be substituted for pulse transformer T1 with suitable circuit
20 adjustments. Each circuit as shown can reliably handle about 3.35 kV across terminals A to B during arcing conditions. Additional stages can be series connected to protect higher voltage power supplies.

Figure 4 illustrates an exemplary winding sense of transformer T1. Transformer T1 may
25 have about 12 turns on each winding – one primary (designated P) and two secondaries (designated S1 and S2 respectively), wound on a ferrite composite core 602. In a preferred embodiment, transformer T1 has about 7 turns on primary winding P and about 12 turns on each of the two secondary windings, S1 and S2. The ferrite composite core 602 of pulse transformer T1 is preferably a Fair-Rite (Fair-Rite Products Corp., P.O. Box J, One

Commercial Row, Wallkill, NY 12589-0288, USA) type 2673002402 or equivalent ferrite toroid.

Figure 5 illustrates a circuit **620** comprised of a series connection of three of the two stage
5 circuits **500** shown in **Fig. 3**. Such an embodiment would include 6 IGBTs and would be
able to reliably handle 10 kV or more across the source terminal **A** and load terminal **B**. In
such a configuration, it is intended that each of the series connected circuits will substantially
simultaneously move from the first operating state providing the lower resistance electrical
10 pathway to the second operating state providing the relatively high resistance electrical
pathway, since the same sensed current flows through the primaries of all transformers T1 in
the various sub-circuits. It should be recognized, however, that small component variations
may result in slight variations in the thresholds of the individual series circuits, such that
transient differences on the order of microseconds in the switching times of the stages may
exist. In such cases, stages remaining in the high resistance state are protected against
15 damage by MOV's VR1 and VR2.

Figure 6 illustrates an arc suppressor circuit **640** comprised of a series connection of three of
the circuits **620** shown in **Fig. 5**. Such an embodiment would include 18 IGBTs and would
be able to reliably handle 30 kV or more across the source terminal **A** and load terminal **B**.
20 It has been shown that additional series connection of stages using good conventional high
voltage packaging and construction techniques is effective to at least 60 kV with 36 total
stages. By using additional series-connected stages and/or by using components with higher
voltage ratings, it is expected that power supplies of up to at least 200 kV can be reliably
protected by arc suppression techniques and circuitry in accordance with the invention.

25

Figure 7 illustrates a circuit **660** including an exemplary 30 kV high voltage power supply
662 driving a load **664** through arc suppressor circuit **640**. An adjustable spark gap **666** can
trigger arc discharges. In high voltage power supply **662**, the stored energy of the supply is
represented by the capacitor **C**. When arc discharges occur at spark gap **666**, the arc

suppressor suppresses each arc within a few msec and prevents the dumping of the charge on capacitor C, permitting the high voltage power supply to recover normal operation within msec.

5 **Figure 8** illustrates a GCIB processing apparatus **700** including improvements according to the invention for reducing the adverse effects of high voltage arcing. An arc suppressor **702** is installed in the high voltage lead between acceleration power supply **140** and the ionizer **122**. The acceleration power supply operates at approximately 40 kV. Arc suppressor **702** has a total of 24 IGBT stages (12 series circuits **500** as shown in **Fig. 3**). During operation
10 of the GCIB processing apparatus, when spurious undesired arcing of the ionizer **122** occurs, the arc suppressor **702** rapidly terminates the arc without dumping the stored charge in the acceleration power supply **140**. **FIGS. 9** and **10**, respectively, show operation with and without the arc suppressor **702**.

15 **Figure 9** is a graph showing voltage and current transients measured at the output of acceleration power supply **140** during an arc transient. This data is measured without the benefit of arc suppressor **702**. It is seen that after 11 msec, the voltage, V_{Acc} , has only recovered to about 60% of the desired 40 kV. Several tens of msec are required for full recovery.

20

Figure 10 is a graph showing voltage and current transients measured in GCIB processing system **700** including an arc suppressor **702**. It is seen that after less than 2 msec following initiation of an arc transient, both normal operating voltage and current have been restored. This is due to the quick interruption of the arc and the prevention of the dumping of the
25 stored charge of the acceleration power supply **140** during the suppressed arc.

Although the circuits employed in the invention are described as employing certain specific component elements, it should be realized that a wide variety of other and further

embodiments can be realized within the spirit of the invention by employing similar components with similar or improved ratings.

It is claimed:

1. A transient electrical arc suppression circuit, comprising:
 - a source terminal for connection to an electrical power source;
 - a load terminal for connection to an electrical load;
 - at least one active semiconductor switch for switching between a first operating state and a second operating state, the first operating state providing a relatively low resistance electrical pathway between the source terminal and the load terminal, and the second operating state providing a relatively high resistance electrical pathway between the source terminal and the load terminal;
 - biasing circuitry responsive to a normal current flowing between the source terminal and the load terminal, for biasing the at least one active switch to operate in the first state;
 - transient sensing circuitry responsive to an increase in the current flowing between the source terminal and the load terminal due to an arc, for switching the at least one active semiconductor switch to operate in the second state so as to suppress the arc; and
 - delay circuitry for momentarily delaying return to the first state from the second state after the arc has been suppressed.
2. The arc suppression circuit of claim 1, wherein connections between the source terminal and an output of a high voltage power supply and between the load terminal and a high voltage terminal of a load are in themselves sufficient to provide one or more of power, control signals and ground reference to the at least one active semiconductor switch, biasing circuitry, transient sensing circuitry, and delay circuitry.
3. The arc suppression circuit of claim 1, wherein current flowing between the source terminal and the load terminal provides all of the operating power and control signals

required by the at least one active semiconductor switch, biasing circuitry, transient sensing circuitry, and delay circuitry.

4. The arc suppression circuit of claim 1, further comprising:
 - a second source terminal connected in series to the load terminal;
 - a second load terminal for connection to an electrical load;
 - a second at least one active semiconductor switch for switching between the first operating state and the second operating state, the first operating state providing a relatively low resistance electrical pathway between the second source terminal and the second load terminal, and the second operating state providing a relatively high resistance electrical pathway between the second source terminal and the second load terminal;
 - second biasing circuitry responsive to a normal current flowing between the second source terminal and the second load terminal, for biasing the second active switch to operate in the first state;
 - second transient sensing circuitry responsive to an increase in the current flowing between the second source terminal and the second load terminal due to an arc, for switching the second active semiconductor switch to operate in the second state so as to suppress the arc; and
 - second delay circuitry for momentarily delaying return to the first state from the second state after the arc has been suppressed.
5. In an ion beam accelerating system, an ion source biasing system, comprising:
 - an ion source having at least one electrode;
 - a high voltage power source for biasing the ion source to a high electrical potential; and
 - a two terminal electrical arc suppression circuit connecting an output of the

high voltage power source to the at least one electrode of the ion source, the electrical arc suppression circuit for automatically detecting and suppressing arcs occurring at the at least one electrode of the ion source and returning to a normal operation.

6. The system of claim 5, wherein the ion source is a gas-cluster ion beam source for forming an ion beam comprised of gas-cluster ions.
7. The system of claim 5, wherein the two-terminal electrical arc suppression circuit is an active circuit.
8. The system of claim 5, wherein connections between the two terminals of the electrical arc suppression circuit are in themselves sufficient to provide one or more of power, control signals and ground reference to the electrical arc suppression circuit.
9. The system of claim 1, wherein current flowing between the two terminals provides all of the operating power and control signals required by the electrical arc suppression circuit.

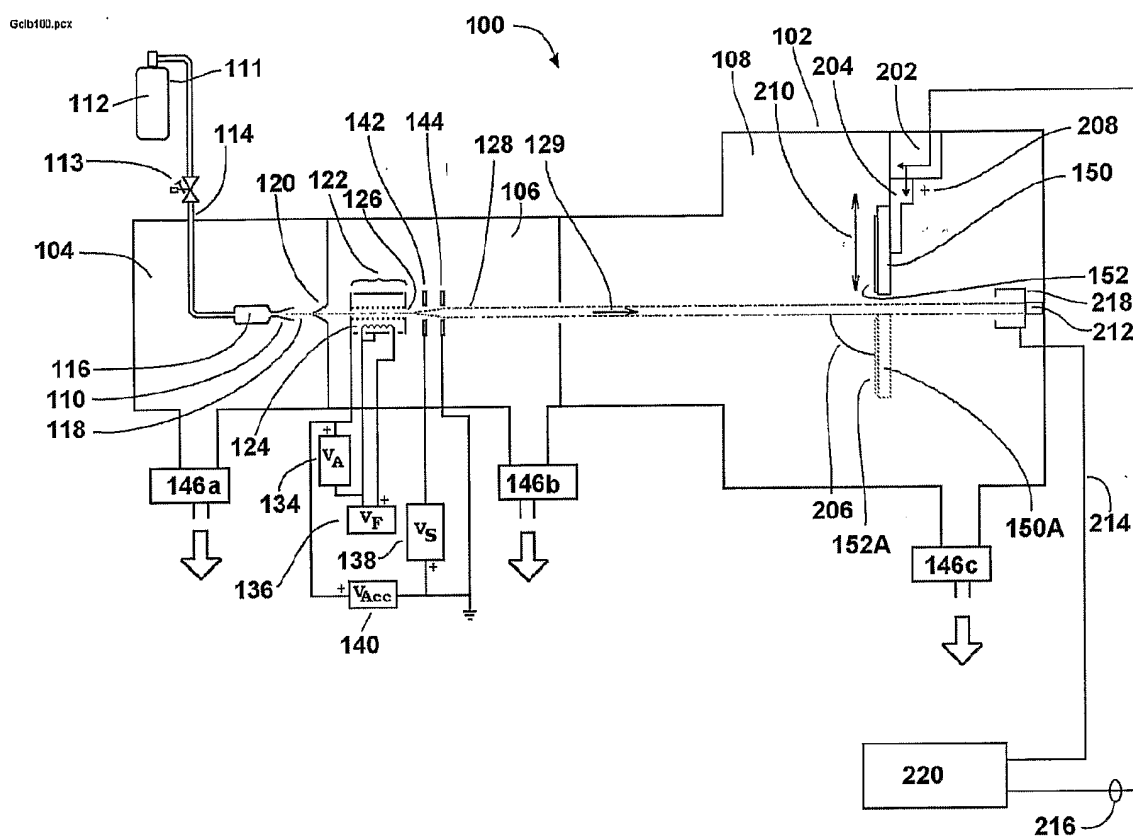


Figure 1 Prior Art

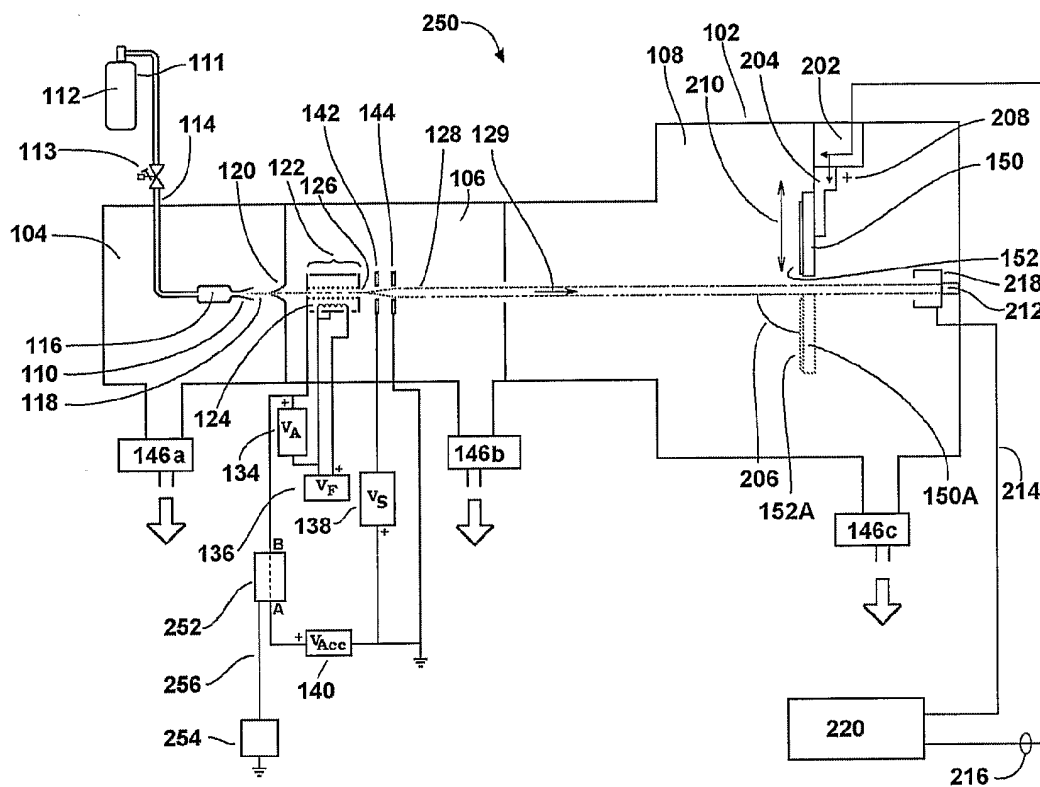


Figure 2 Prior Art

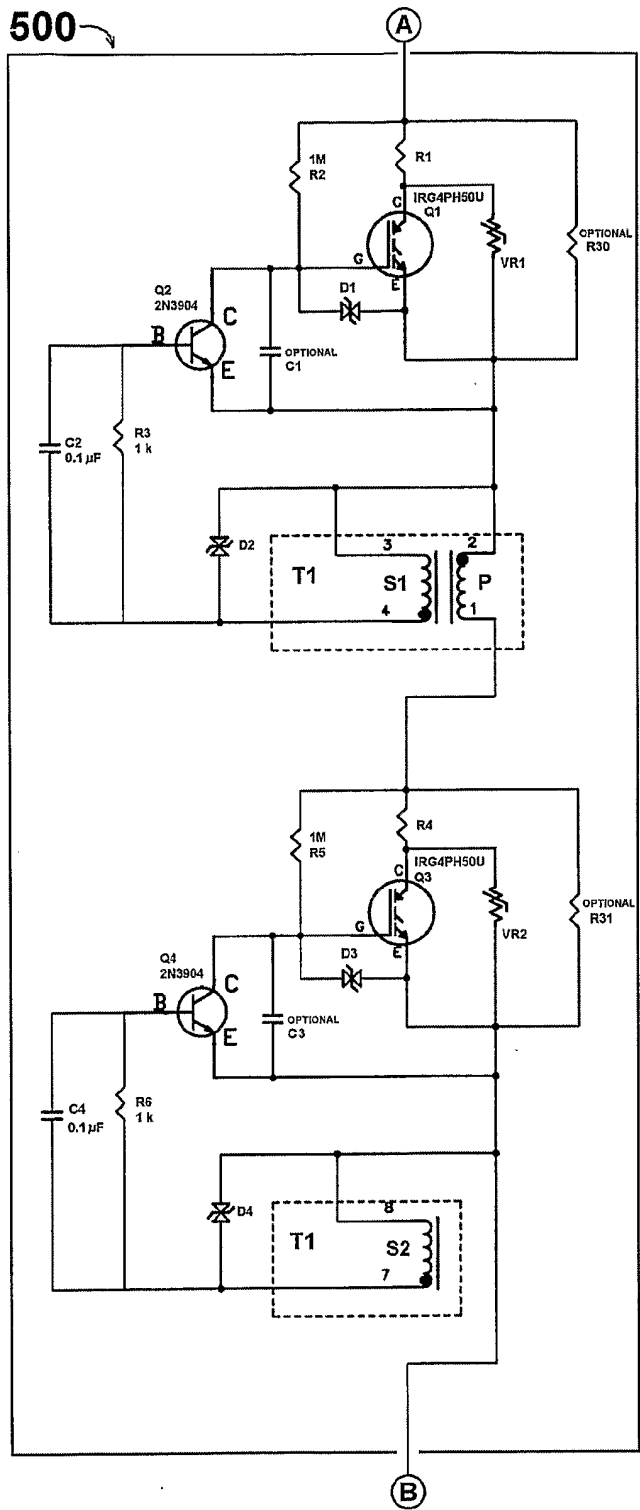


Figure 3

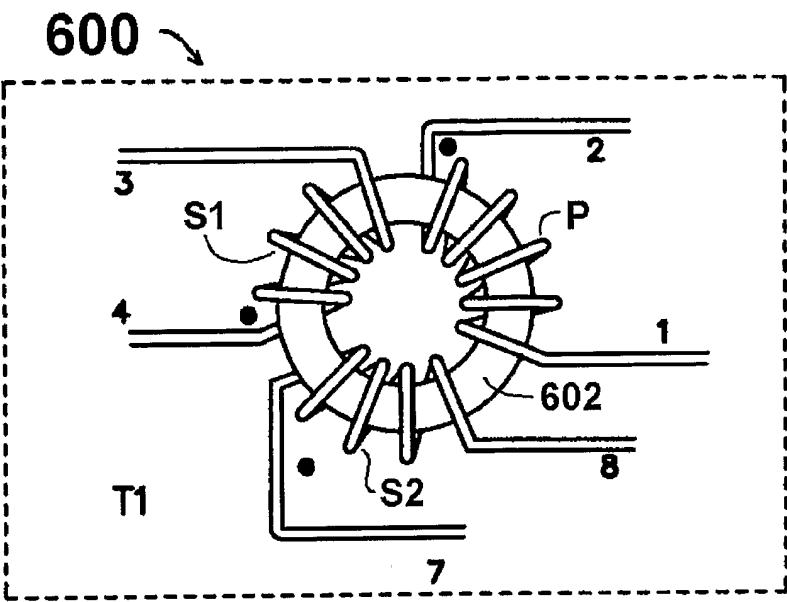


Figure 4

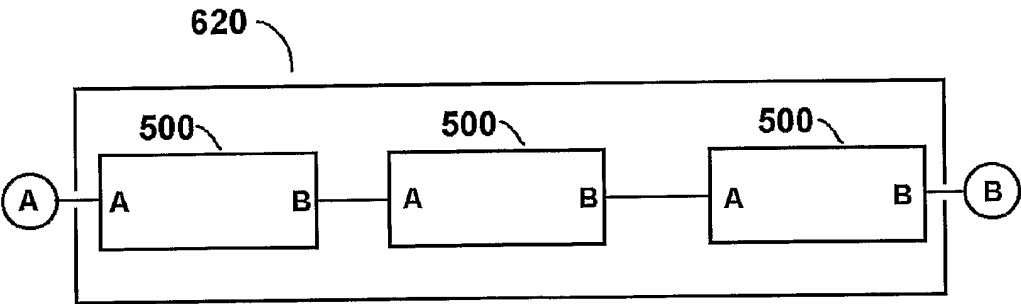


Figure 5

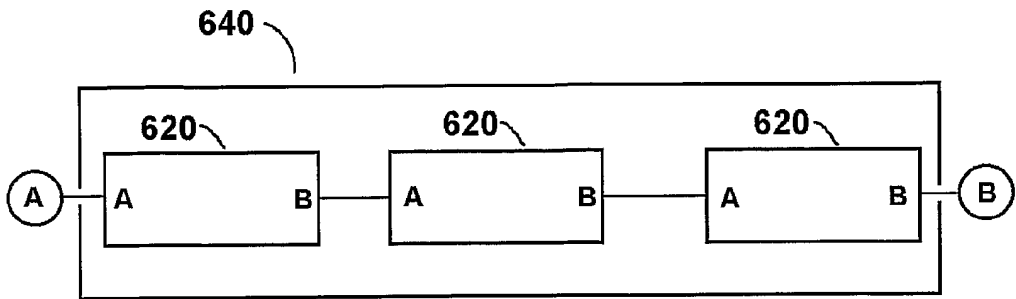


Figure 6

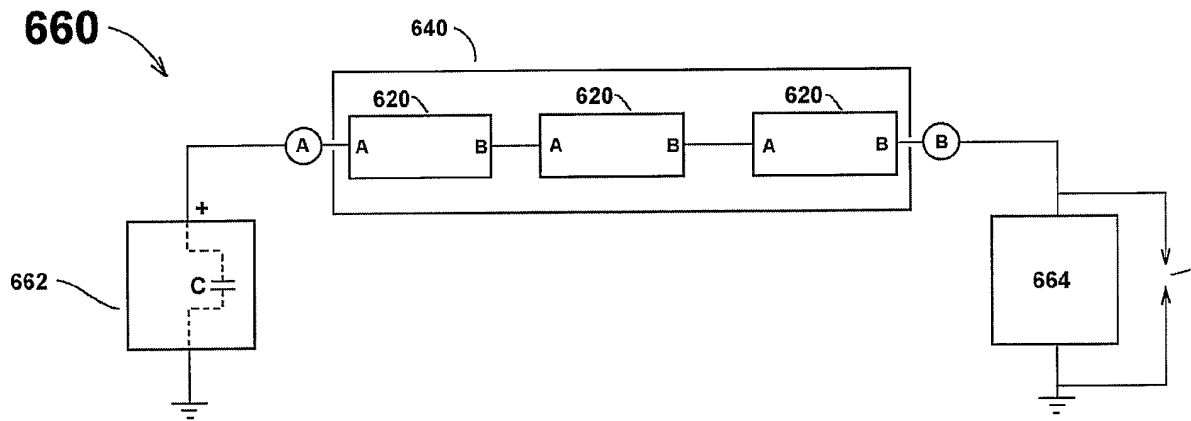


Figure 7

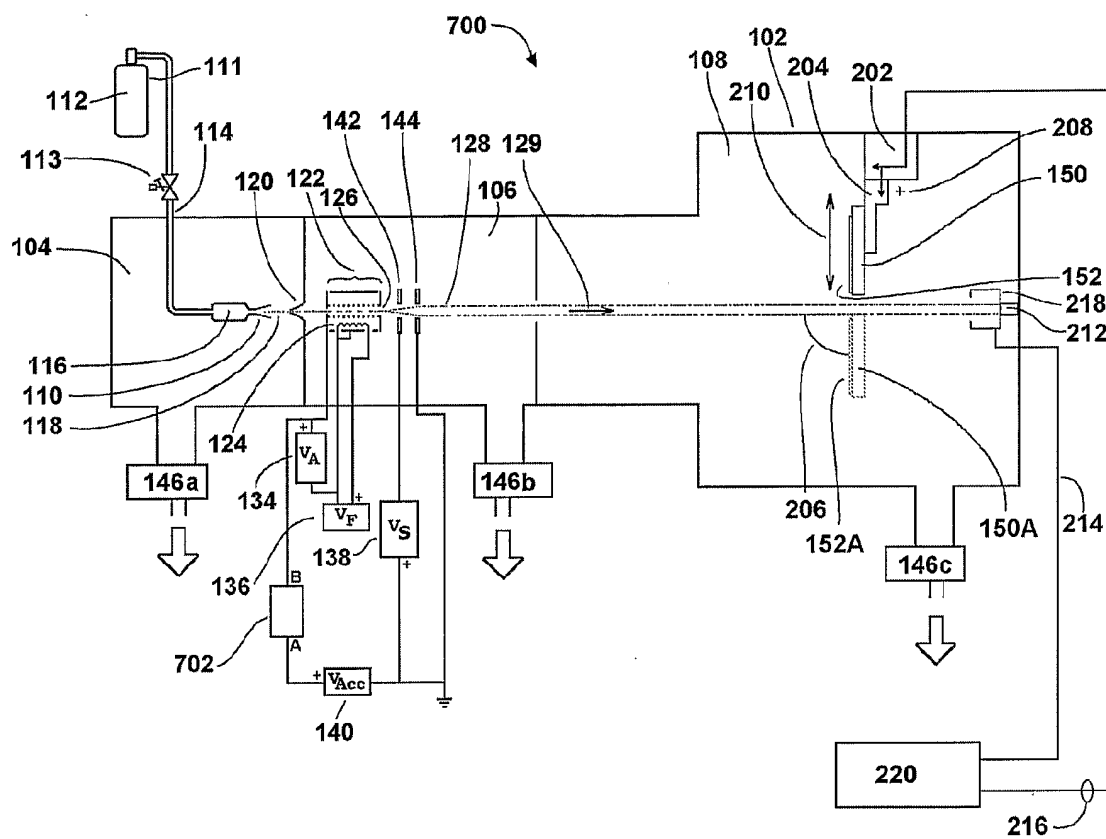


Figure 8

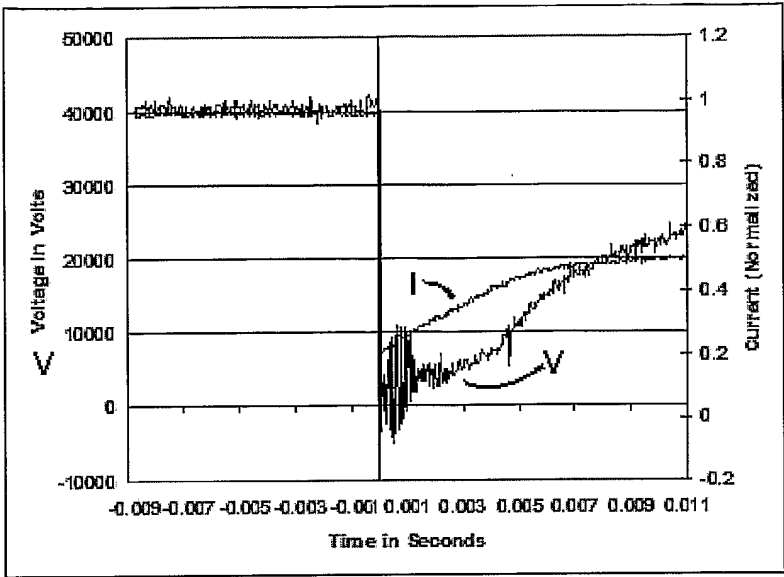


Figure 9

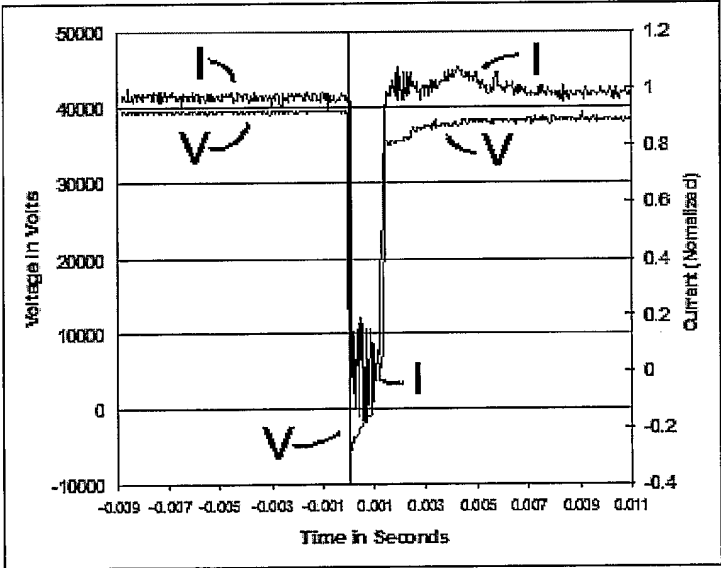


Figure 10