

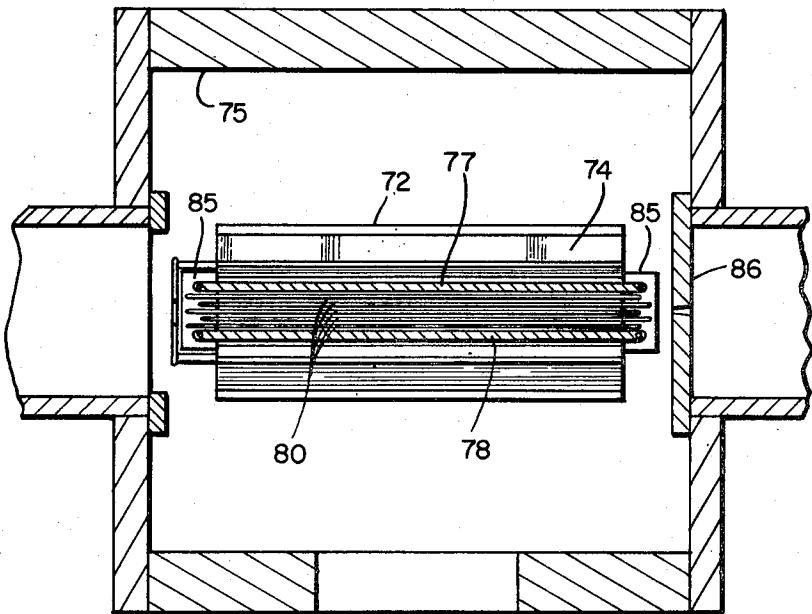
[54] **ION ACCELERATOR EMPLOYING
CROSSED-FIELD SELECTOR**
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[73] Assignee: **Alpha Industries, Inc.**, Woburn,
Mass.
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[52] U.S. Cl. **250/296, 250/398, 313/63**
[51] Int. Cl. **H01j 39/34**
[58] Field of Search 250/41.9 DS, 41.9 ME, 49.5 T;
313/63

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Primary Examiner—William F. Lindquist
Attorney, Agent, or Firm—Kenway, Jenney & Hildreth

[57] **ABSTRACT**
In the ion accelerator disclosed herein, the desired ion species is selected by means of a filter or selector of the crossed-field type which is self-focusing on at least one axis and which permits ion energy to be easily varied while maintaining focus and desired species selection. In the selector, the electric field provided has a strength which, on the centerline of the beam, is proportional to the square-root of the ion energy and has a gradient, in the direction of the field, which is proportional to the ion energy.

7 Claims, 7 Drawing Figures



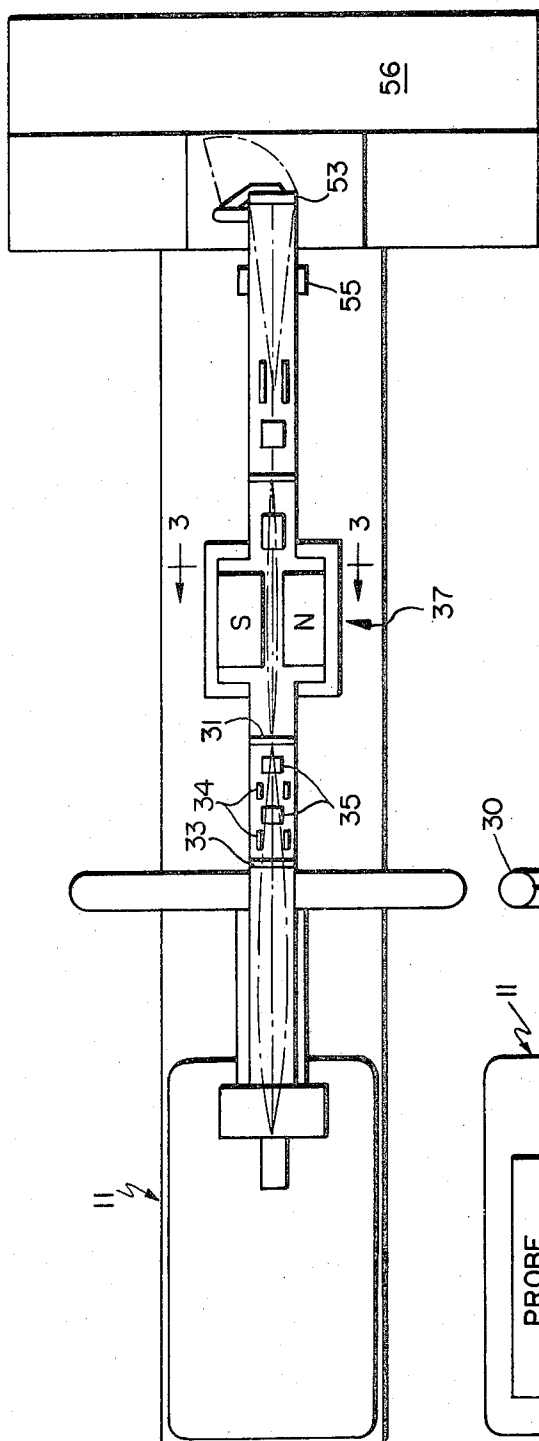


FIG. 1

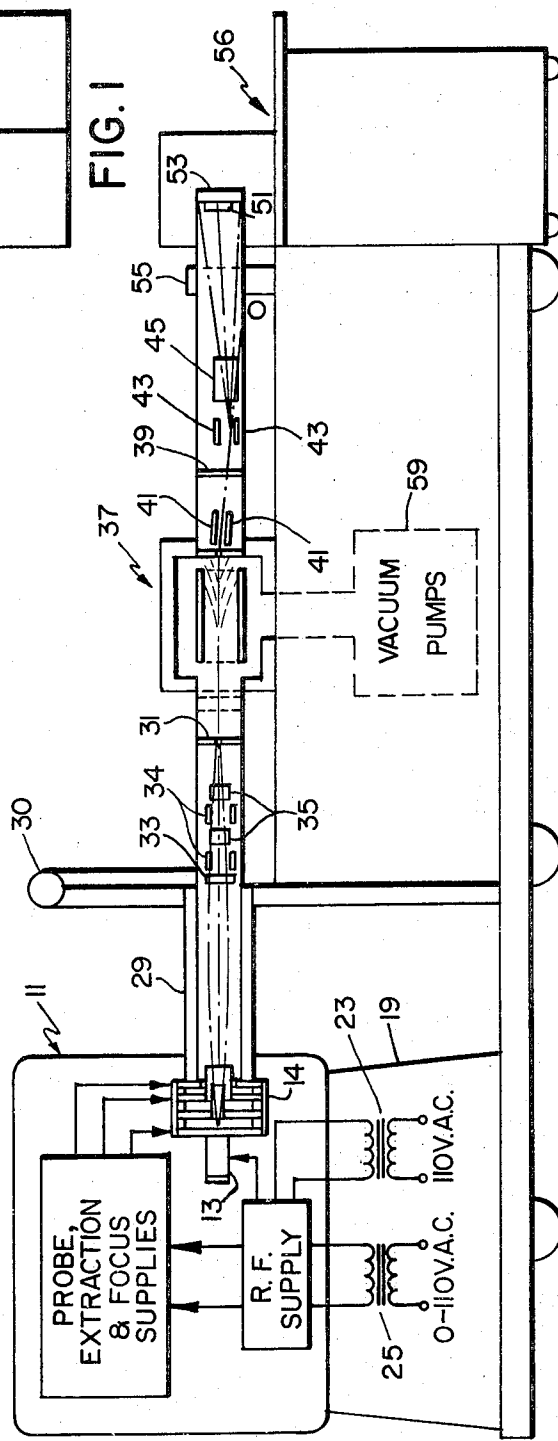


FIG. 2

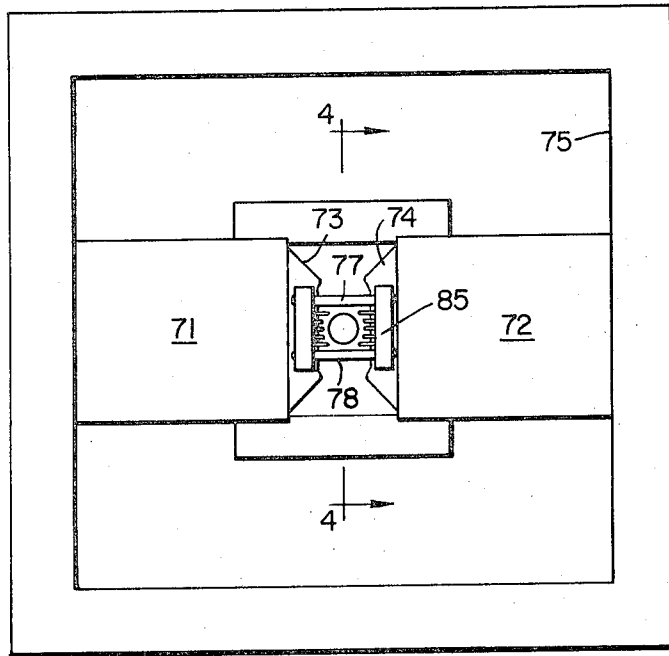


FIG. 3

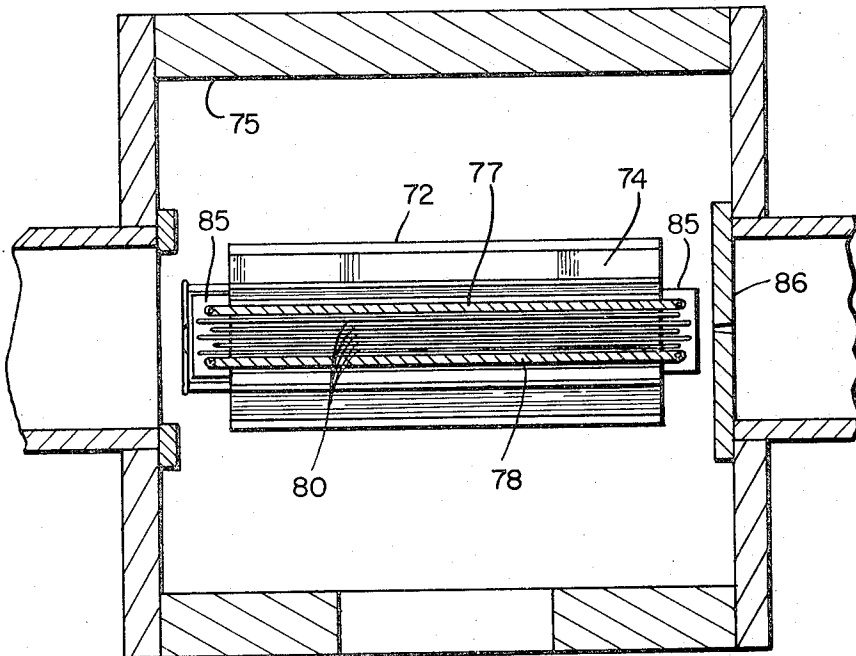


FIG. 4

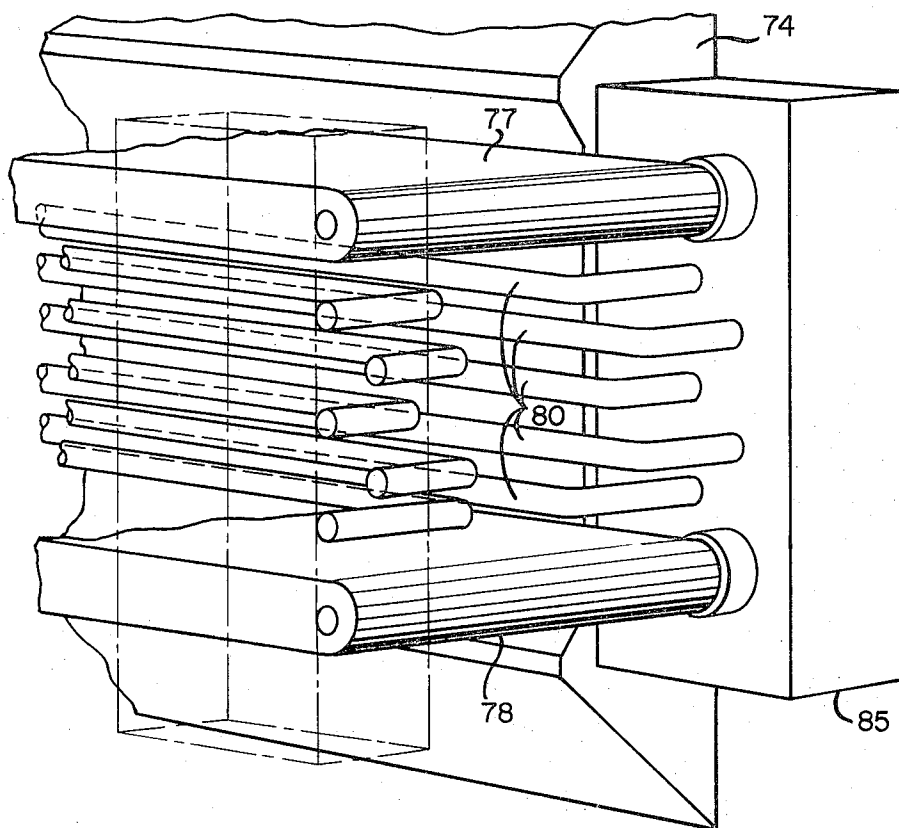


FIG. 5

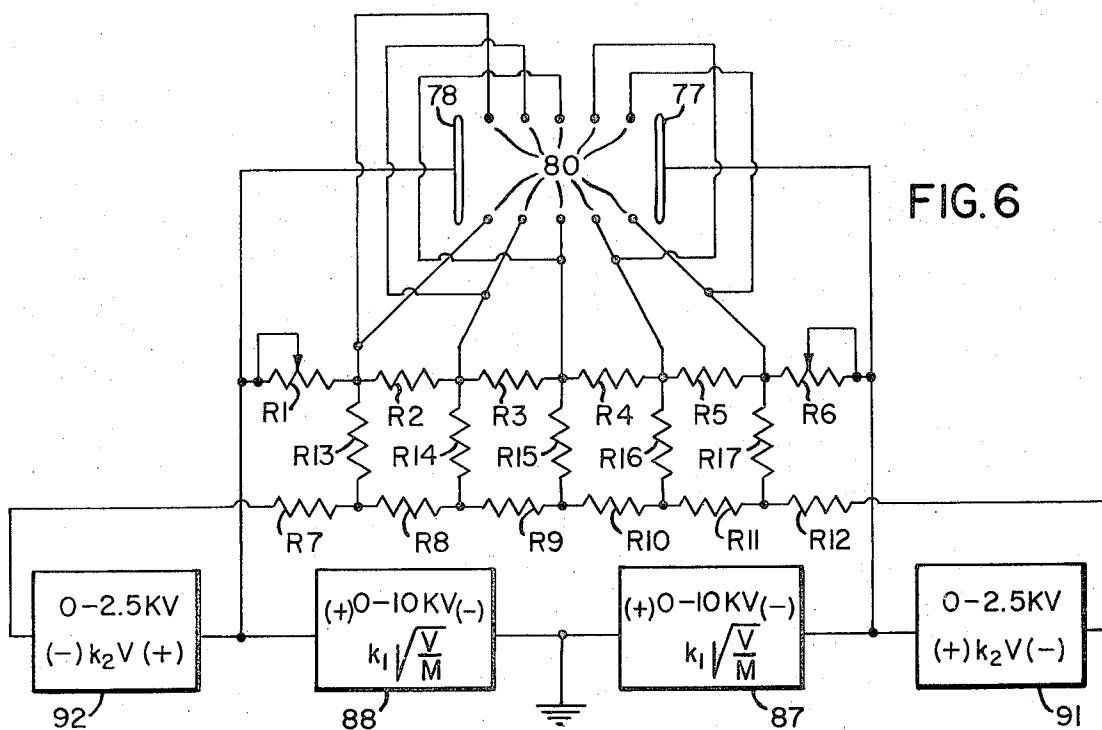


FIG. 6

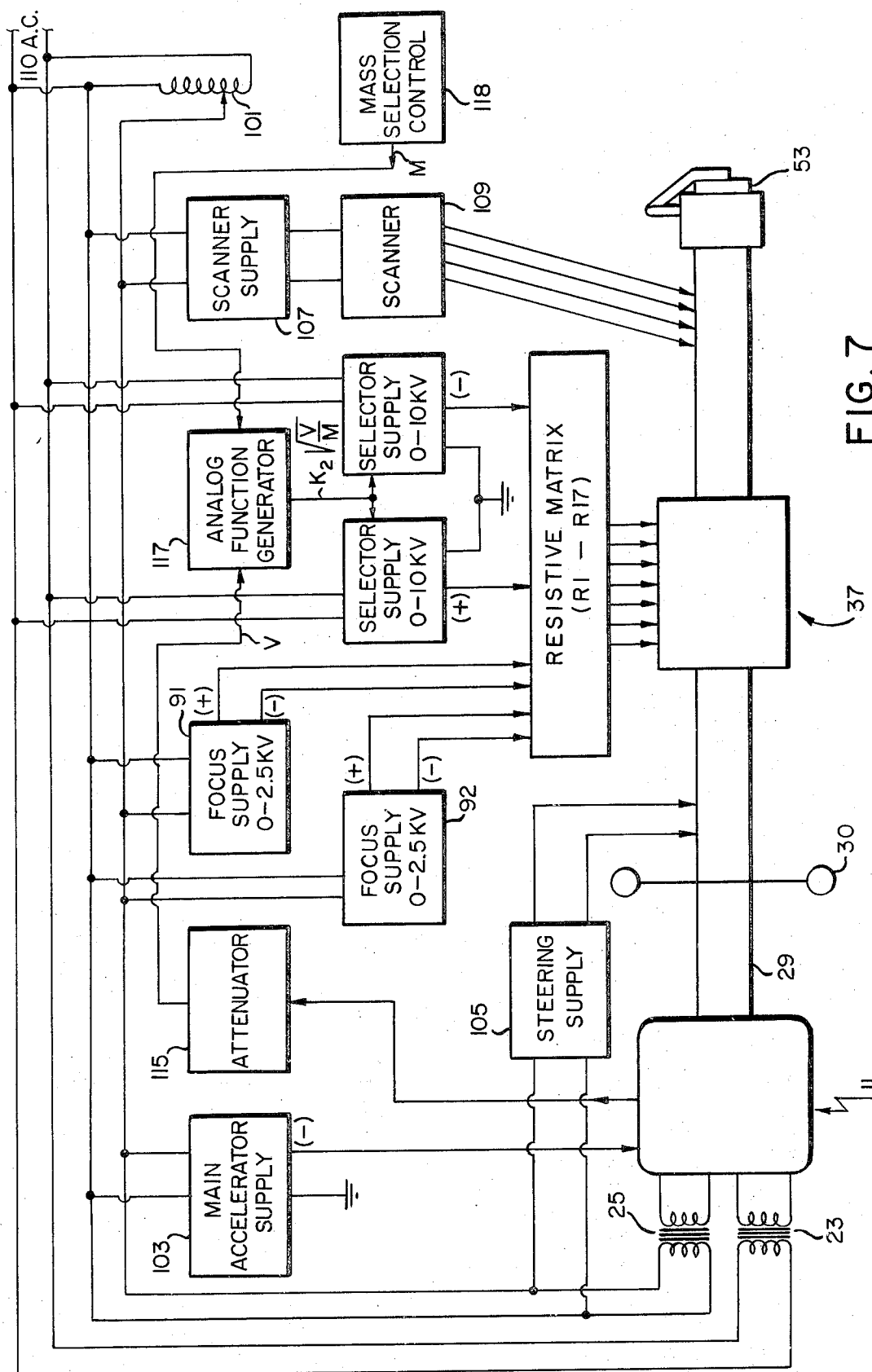


FIG. 7

ION ACCELERATOR EMPLOYING CROSSED-FIELD SELECTOR

BACKGROUND OF THE INVENTION

In most ion accelerator systems known heretofore, the final ion species selection has been accomplished by means of an analyzer magnet which spreads the various species which may be present into a spectrum so that the desired species can be selected by means of an exit slit, the unwanted species being blocked. Typically, the analyzer employed is an electromagnet so that magnetic field strength could be varied so as to bring the desired species component into registration with the slit. Since the magnet structures involved typically exhibit considerable hysteresis, the current setting required to give a needed field strength was not readily repeatable with any degree of accuracy. In such systems, considerable adjustment time is therefore required either to change the species being selected or the beam energy for a given species, since an empirical adjustment of the current value supplied to the analyzing magnet coil is needed. This makes analog control of the analyzers difficult, and rapid mass spectrum scanning with an oscilloscope display impossible. While various crossed-field analyzers have also been devised, these structures have typically not been dynamically self-focusing and have not facilitated adjustments of ion energy or changes in selected species.

While such readjustment procedures do not present inordinate problems in a physics laboratory, where the work being done is experimental in nature, the increasing use of ion accelerators in the fabrication of electronic semiconductor components by ion implantation makes it highly desirable to provide an accelerator which is highly flexible in actual operation and in which the ion beam parameters can be readily changed without elaborate readjustment.

Among the several objects of the present invention may be noted the provision of an ion accelerator employing a novel ion species selector in which the ion energy may be easily changed or adjusted; the provision of such an accelerator in which the ion species selected may be easily changed; the provision of such a system in which ion focus is maintained during changes in ion energy or ion species; the provision of such a system in which ion species selection is not disturbed by changes in ion energy; the provision of such a system which is highly reliable and which is of relatively simple and inexpensive construction.

SUMMARY OF THE INVENTION

Briefly, the present invention relates to an ion accelerator in which the accelerating voltage and thus the energy imparted to the ions being accelerated is adjustable. The accelerator employs an ion species selector of the crossed-field type. A substantially constant and fixed magnetic field is provided perpendicular to the beam over a predetermined distance and an electric field is generated over that same distance, the electric field being substantially perpendicular to both the magnetic field and to the beam. This field strength can be rapidly modulated to generate a mass spectrum for diagnostic purposes. The strength of the electric field on the beam axis is proportional to the square root of the ion energy and the field has a gradient which is substantially directly proportional to ion energy. By controlling

the electric field in this manner, initial settings of beam focus and ion species selection are maintained even though the ion energy is varied.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view, with parts broken away, of an ion accelerator employing a crossed-field selector in accordance with the present invention;

FIG. 2 is a side view, with parts broken away, of the ion accelerator of FIG. 1;

FIG. 3 is a sectional view of the ion selector of the present invention taken substantially on the line 3—3 of FIG. 1;

FIG. 4 is a sectional view of the selector taken substantially on the line 4—4 of FIG. 3;

FIG. 5 is a perspective view on a large scale showing the arrangement of field shaping electrodes employed in the ion selector of FIGS. 3 and 4;

FIG. 6 is a schematic circuit diagram of the circuitry provided for energizing the ion selector of FIGS. 3—5; and

FIG. 7 is a block diagram of circuitry for energizing the various power supplies employed in the operation of the ion accelerator of FIGS. 1 and 2.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGS. 1 and 2, the ion accelerator illustrated there is arranged so that ions are accelerated from an ion source maintained at a high voltage with respect to ground to a utilization system or target which is maintained at ground potential. This provides ease in manipulation of the target. In FIGS. 1 and 2, the high voltage terminal is indicated generally at 11 and includes an ion source 13 which may conveniently be of the r.f. type. As is conventional, the terminal 11 comprises a relatively large housing 12 within which the various components associated with the generation of the source ions are contained, the whole terminal assembly being then raised to the main accelerating voltage with respect to ground. For this purpose, the terminal housing 12 preferably has a rounded configuration so as to minimize field gradients and is mounted on a high voltage insulating pedestal 19. The r.f. power supply 15 normally associated with the source 13 is mounted within the terminal housing 12 as are the probe, extraction, and focus power supplies, indicated together at 16, which are typically associated with the ion gun assembly 14.

As is described in greater detail hereinafter, certain components within the terminal, such as the r.f. supply 15, blowers, etc., are energized at a level which is substantially the same for different accelerating voltages, while certain other components, such as the supplies 16 which affect ion energy and focus, are energized at a level which varies substantially in proportion to the accelerating voltage. To this end, the insulating pedestal 19 preferably encompasses two isolating transformers, i.e. as indicated diagrammatically at 23 and 25. These transformers are provided principally to provide isolation rather than any incidental voltage level transformation and thus the insulation between the primary and secondary windings thereof must be able to withstand the full acceleration potential.

Ions extracted from the source 13 by the ion gun assembly 14 are accelerated by the main accelerating potential as they travel down a main accelerating tube 29. Tube 29 is preferably shielded in the manner described in my copending application Ser. No. 830,274 filed June 4, 1969 and entitled Shielding For A Particle Accelerator. Preferably, a large electrostatic shield 30 is provided between the main accelerator portion and the ion selecting and utilization means which are downstream of the accelerator tube. Ions emerging from the accelerating tube 29 are focused on a slit 31 by means of an electrostatic lens comprised of the ion gun 14 and accelerator tube 29. A secondary electron suppressing electrode is located at 33. Preferably, conventional electrostatic steering electrodes 34 and 35, similar to deflection electrodes, are provided for bringing the beam directly into exact impingement and alignment upon the slit 31 so that maximum throughput efficiency is obtained.

Ions emerging from the slit 31 pass through an ion species selector 37 which is described in greater detail hereinafter. In accordance with the present invention, the selector 37 incorporates a self-focusing feature so that the beam of ions passed by the selector are focused in the plane of a second slit 39. However, the level of the slit is preferably slightly below a direct line through the selector 37, the desired ions being deflected slightly downwardly before reaching the plane of the slit by deflection electrodes 41. In this way, only ions of the desired species pass through the slit and the neutral beam is blocked by impingement upon the slit structure.

The ion beam of the selected species emerging from slit 39 enters a scanner section having vertical and horizontal deflection electrodes, 43 and 45 respectively. For semiconductor fabrication by ion implantation, these electrodes are driven with triangular voltages so as to generate a Lissajous figure or raster which provides equal ion flux density over the target area. The vertical deflection electrodes 43 are preferably biased to provide a net upwards deflection which offsets or compensates for the downward inclination introduced by the neutral beam-eliminating deflection electrodes 41, and further removes neutralized particles.

In the embodiment illustrated, which is adapted for semiconductor fabrication by ion implantation, the final ion beam raster is directed onto a sample holder 51 which is mounted on a door 53 at the end of the accelerator. In order that samples may be changed without admitting atmospheric pressure to the entire accelerator system, the sample station can preferably be blocked off from the rest of the system by means of a lock valve, indicated diagrammatically at 55. Preferably also, the sample holder area is surrounded by a so-called clean bench which may in turn be incorporated into an operating console for the accelerator, e.g. as indicated at 56 at the utilization end of the accelerator.

A conventional vacuum pumping system is indicated generally at 59. The system is conveniently pumped in the vicinity of the selector 37 which is physically near the mid-point of the accelerator assembly, so that differential residual pressures are minimized.

The selector 37 itself is illustrated in FIGS. 3, 4 and 5 and, in general, is of the crossed-field type, that is, it employs both a magnetic field and an electric field, these fields being essentially perpendicular to each other field and to the central axis of the ion beam. A

pair of permanent magnets 71 and 72, provided with respective field-shaping pole pieces 73 and 74, are employed for generating a uniform transverse magnetic field between the pole pieces. The opposite ends of the magnets 71 and 72 are supported by a housing 75 constructed of a highly permeable magnetic material which completes the magnetic circuit. As may be seen in FIG. 4, the magnets and the pole pieces are relatively long in the direction paralleling the ion beam so that the magnetic field is applied to the beam over a substantial and predetermined distance.

Mounted within the gap between the pole pieces 73 and 74 are a pair of electrode plates 77 and 78 arranged for generating an electric field which is essentially perpendicular to the magnetic field and also perpendicular to the axis of the ion beam. As may be seen in FIGS. 3, 4 and 5, a plurality of elongate field-shaping electrodes 80 are mounted adjacent each magnetic pole face between the electrode plates 77 and 78. The individual electrodes 80 extend essentially parallel to the ion beam axis and the group or series adjacent each pole face is arranged in a slightly arched configuration between the electrode plates 77 and 78. The field-shaping electrodes 80 are preferably constructed in the form of stiff but light titanium tubes so that they can be supported at their ends without substantial sagging. As may be seen best in FIG. 5, the electrodes adjacent each pole face are supported relative to the respective pole piece by means of insulating blocks 85 mounted at the ends of the pole piece. The plate electrodes 77 and 78 are also mounted on the insulating blocks 85, as illustrated. If desired, the plates 77 and 78 may be provided with cooling tubes to carry away the heat generated by the impingement of deflected ions.

As mentioned previously, the selector 37 employs a magnetic field which is essentially fixed and constant in conjunction with an orthogonal electric field which is both itself variable in strength and has a variable gradient. The circuit diagram of FIG. 7 illustrates the arrangement of variable power supplies and resistive mixing/dividing networks employed in the illustrated embodiment for energizing the array of electrode plates and rods to obtain the field characteristics of the present invention.

As indicated diagrammatically in FIG. 6, equal and opposite potentials are applied by respective d.c. supplies 87 and 88 to the electrode plates 77 and 78 with respect to ground. These d.c. supplies are controlled, as described in greater detail hereinafter, so as to provide voltages which are substantially proportional to the square root of the main accelerating voltage and inversely proportional to the square root of the mass of the selected ion species. The accelerating voltage is designated V and thus each of these voltages may be designated $k_1 \sqrt{V/M}$. The value of k_1 will depend upon various design parameters including the strength of the magnetic field in the selector 37 and the length along the beam axis over which the selector fields are operative, as well as upon the exact configuration of the selector generally. Assuming that a uniform electric field was generated between the plates 77 and 78, the ion selector as thus far described would be an essentially conventional crossed-field selector. In such a detector, ions tend to be deflected in one direction by the magnetic field and in the opposite direction by the electric field. These countervailing forces can be adjusted to balance for a given or selected ion species but other

ion species will undergo a net deflection. Thus, only the selected ion species will pass straight through the selector while other species will be deflected and can be blocked by an appropriate slit structure. In the illustrated apparatus, such a slit is indicated at 86 in FIG. 4.

In accordance with the practice of the present invention, the electric field within the selection region is not uniform but, rather, is caused to exhibit a gradient, the magnitude of the gradient being essentially directly proportional to the main accelerating voltage and thus also to ion energy. In the embodiment illustrated, a gradient or distortion of the uniform field in the selection region is provided by applying, to each field-shaping electrode, a respective potential which is not proportionally related to its position between the plates 77 and 78. The extent of the distortion or departure from a linear voltage gradient is in turn controlled in substantially direct proportion to the main acceleration voltage or ion energy. In the diagram of FIG. 6, isolated d.c. supplies 91 and 92 provide isolated d.c. voltages which vary substantially in direct proportion to the accelerating voltages. Each of these voltages can thus be designated k_2 (V), the value of k_2 being also dependent upon physical dimensions and other design parameters. The sources 91 and 92 are connected, as illustrated, so as to respectively add or subtract from the voltages applied to the plates 77 and 78 by the d.c. supplies 87 and 88. The voltage between the plates 77 and 78 is applied to a voltage divider comprising resistors R1-R6 while the compound voltage obtained across all four sources is applied to a voltage divider comprising resistors R7-R12.

As will be understood, the voltage between the plates 77 and 78 would, if linearly divided, provide voltages to the respective field-shaping electrodes 80 which would produce a substantially linear voltage gradient and uniform field, assuming that the electrodes are substantially uniformly spaced between the plates. In accordance with the present invention, a field gradient is established by mixing respective portions of the compound voltage with respective portions of the plate supply voltage, through coupling resistors R13-R17, the various resultant mixed voltage being then applied to the respective field-shaping electrodes. In a particular embodiment of the apparatus providing entirely satisfactory operation with ions of boron and phosphorous, the supplies 87 and 88 provided voltages from 0 to 10 kilovolts, positive and negative, and the supplies 91 and 92 provided voltages from 0 to 2.5 kilovolts. These latter supplies, however, were constructed having 10 kilovolt capacity so that sufficient isolation and insulation qualities were provided to permit their outputs to be, in effect, "floated" at the potentials provided by the supplies 87 and 88.

The effect on the field by the current components obtained from the network R7-R12 driven by the supplies 91 and 92 is to produce an essentially uniform electric field gradient in the direction of the main electric field, the uniformity of the gradient being substantially a function of the isolation provided by the resistors R13-R17. Satisfactory isolation was obtained when the resistors R13-R17 had values approximately 10 times those for resistors R7-R12. In the particular embodiment identified above, values of 200 megohms for resistors R13-R17 and 25 megohms for resistors R1-R12 were used. Preferably, the values of the resistors R1

and R5 is adjustable around a nominal value of 25 megohms so as to permit an initial adjustment of the field with respect to the electrode plates 77 and 78.

The effect of the field gradient generated in accordance with the present invention is to produce a focusing of the ion beam on the transverse axis which is in the direction of the electric field. Thus, the beam can both enter and exit the ion selector through relatively narrow slits without any need for a separate electrostatic lens system. As will be understood by those skilled in the art, the strength of the field gradient needed to obtain focusing will depend substantially directly upon the energy or velocity of the ions passing through the selector. Thus, by providing a field gradient which tracks or remains in proportion to the ion energy, i.e. by means of the supplies 91 and 92, it can be seen that the system is caused to automatically remain in focus even though the accelerating voltage is changed. Further, since the main component of the electric field, i.e. the analyzing component, is caused to track or remain proportional to the square root of the ion energy, it will be seen that the selector will continue to pass the same preselected ion species, even though ion energy is varied by changing the main accelerating voltage. In other words, this arrangement causes the electric field on the centerline or central axis of the ion beam to remain proportional to the square root of the ion energy.

FIG. 8 diagrammatically illustrates the manner in which the various voltage supplies employed in the accelerator are energized so as to facilitate easy adjustment of the accelerating voltage and ion energy and the changing of the mass number of the particular ions being accelerated. While feedback control of the various supply voltages in response to a common control voltage could be provided as will be apparent to those skilled in the art, the response of most high voltage supplies to variations in a.c. input voltage is linear or consistent enough so that common or proportional variation of a plurality of electrostatically significant voltages can conveniently be provided by varying the common a.c. input voltages to the different power supplies providing those voltages. In the circuit of FIG. 7, an autotransformer or variac 101 is employed for providing a readily variable a.c. supply voltage. The main accelerator power supply 103 is energized from this variable voltage and charges the ion source terminal 11 of the accelerator to a relatively high d.c. potential with respect to ground. In order to maintain a substantially constant set of focus parameters and deflection geometries as the accelerating voltage is varied, all focus deflection and scanning supplies are also energized from the adjustable a.c. source leads. These supplies include a supply 105 which provides the voltages for the steering electrodes 34 and 35, the focus supplies 91 and 92 which are responsive for the focusing field gradient within the selector 37 and the supply 107 which provides source voltages to the raster scanner 109. The raster scanner 109 is preferably of a type which will generate suitable triangular waveforms for scanning the ion beam, the peak-to-peak values of those waveforms being proportional to the supply voltages being provided to the scanner. The scanners disclosed in my co-pending applications Ser. No. 835,580 filed June 23, 1969 and entitled Beam Scanner With Deflection Plate Capacitance Feedback For Producing Linear Deflection (U.S. Pat. No. 3,588,717) and Ser. No. 88,406

filed Nov. 10, 1970 entitled Scanning System For Ion Implantation Accelerators are of this latter type.

Since the exact ion energy of the beam emerging from the accelerator tube 29 will depend not only upon the main accelerator voltage but also upon some of the various electrostatic accelerating and focusing potentials employed in the ion gun 14 and since beam focus depends on the relationship between these voltages and the main voltage, the variable a.c. voltage obtained from variac 101 is also provided, through the transformer 25 described previously, to the appropriate power supply circuits 16 within the source terminal 11 so that the voltages provided thereby also may be essentially scaled to the main accelerator voltage. As mentioned previously, various heater, blower and other power supply voltages required within the conventionally constructed source terminal 11 may be required to remain substantially constant and thus the original or non-varying a.c. supply current is provided to the terminal, i.e. through the isolating transformer 23 also mentioned previously.

As described previously, the electrostatic field provided on the centerline of the selector is to be controlled as a square root function of both the ion energy and mass. In order to generate such a voltage, a low voltage signal proportional to the ion energy is derived by means of a high voltage attenuator 115. Since, as noted previously, ion energy varies somewhat as a function of probe and extraction voltages as well as the main accelerating voltage, the attenuator 115 preferably senses the actual probe or plasma potential, rather than simply the main accelerating potential. In this way, a somewhat more accurate analog of actual ion energy is obtained. This control signal is applied to an analog computational circuit indicated at 117. Likewise, an operator-adjustable control signal is provided, as indicated at 118, to the analog computational circuitry 117. This control signal may be provided by a potentiometer incorporated into the control console which is then designated the mass selection potentiometer. The amplitude of this signal is designated M.

The analog computational circuitry 117 operates to generate a control signal which is proportional to the square root of the ratio of the two input control signals provided thereto. In other words:

$$V_{out} \propto \sqrt{(V/M)}$$

Circuitry for performing such analog computation is well known and is not described in detail hereinafter. This control signal is then amplified to the relatively high positive and negative potentials required to perform electrostatic selection by the supply circuits 87 and 88. As may be understood, these supplies are essentially amplifiers or regulated power supplies which are responsive to the control signal provided thereto and which draw power from the constant voltage a.c. supply leads.

As the various focusing, deflection and scanning supplies are all caused to vary in proportion to the main accelerator voltage, and since the electrostatic field required to perform a given focusing or deflection operation varies essentially directly in proportion to the energy of the particle which is to be deflected or focused, it can be seen that the path of ions emitted from the source terminal 11 will remain substantially constant as the main accelerator supply voltage is varied. Likewise, since the novel selector of the present invention per-

mits focusing and selection parameters to be relatively independently controlled and since the selector supply voltage varies in proportion to the square root of both the mass and energy of the ions being provided to the selector, it can be seen that the species passed by the selector will remain essentially unchanged as accelerator voltage is varied. Thus, the accelerator voltage can be adjusted or programmed to obtain various implantation profiles while the system is actually in operation and thus repetitive adjustment procedures can be avoided. Similarly, if it is desired to change the material which is being implanted, the selector can be adjusted to pass the particles of the new atomic weight material being provided by the source simply by changing a potentiometer which is calibrated linearly in mass units. Thus, even though a new ion source material is introduced at the source terminal 11, a complete readjustment of the accelerator is not required. As will be understood, this greatly facilitates the use of the accelerator of the present invention in the use of ion implantation as a semiconductor production technique.

As mentioned previously, the crossed magnetic and electric fields operate on the ion beam over a substantial distance and it is only necessary that the focusing gradient of the present invention be present on the average over the entire duration of the ions within the selector. Thus, a time-division or space-division averaging can be employed, in place of the resistive mixing of the embodiment illustrated, by providing field-shaping electrodes of graded lengths in complementary sets.

In view of the foregoing, it may be seen that several objects of the present invention are achieved and other advantageous results have been attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it should be understood that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. In an ion accelerator in which the energy imparted to the ions being accelerated to form an ion beam is adjustable, a linear ion selector comprising:

means for generating, over a predetermined straight line distance along the beam, a substantially constant and fixed magnetic field, which field is substantially perpendicular to said beam;

means for generating, over said distance, an electric field which is substantially perpendicular to both said magnetic field and to said beam, the strength of said electric field on the center line of said beam being varied substantially in proportion to the square-root of the chosen ion energy, said field having a gradient in the direction of the electric field which is, on the average over said distance, varied substantially in direct proportion to the chosen ion energy.

2. Apparatus for providing ions of a preselected species at a selected energy level which is adjustable, said apparatus comprising:

an ion source for providing ions of said preselected species;

accelerating means;

means for energizing said accelerating means including a first voltage source providing an accelerating voltage which varies substantially in direct proportion to said selected energy, thereby to provide a

beam including a substantial proportion of ions of said preselected species;

a linear ion selector having means for generating a magnetic field which is perpendicular to said beam and having also electrode means for generating an electric field which is perpendicular to both said beam and said magnetic field; and

means for energizing said electrode means including a second voltage source which is interconnected with said electrode means to provide, on the centerline of said beam, an electric field which is varied substantially in proportion to the square root of said selected energy and including also a third voltage source interconnected with said electrode means to provide a field gradient which is varied substantially in direct proportion to said selected energy.

3. An ion accelerator comprising:

an ion source for providing ions of a selectable species having a mass M ;

accelerating means associated with said source;

means for energizing said accelerating means to form a beam of ions, including a substantial proportion of said selected species, having an adjustable energy V ;

magnet means, including a pair of pole faces lying on opposite sides of said beam, for providing a transverse magnetic field of predetermined intensity through which said beam passes;

a pair of plates on opposite sides of said beam, between said pole faces;

means for applying equal and opposite potentials to said plates, said potentials being varied substantially in proportion to $\sqrt{(V/M)}$, thereby to provide, on the beam axis, an electric field of corresponding strength, which electric field is substantially perpendicular to both said magnetic field and the beam axis;

adjacent each pole face, a series of elongate field-grading electrodes which extend substantially parallel to the beam axis and are spaced apart between said plates, the number of electrodes in the two series being the same whereby the corresponding electrodes in the two series form pairs, the paired electrodes being connected together so as to be at substantially equal potentials;

means for providing to each pair of electrodes a voltage which is a mixture of a voltage which is proportional to the voltage between the plates and the relative spacing of the pair together with a voltage which is varied in proportion to V and the relative spacing of the pair, thereby to provide an electric field gradient across said beam, which gradient is proportional to V and is parallel to the electric field.

4. An ion accelerator comprising:

an ion source for providing ions of a selectable species having a mass M ;

accelerating means associated with said source;

means for energizing said accelerating means to form a beam of ions, including a substantial proportion of said selected species, having an energy V ;

magnet means, including a pair of pole faces lying on opposite sides of said beam, for providing a transverse magnetic field of predetermined intensity through which said beam passes;

a pair of plates on opposite sides of said beam, between said pole faces;

adjacent each pole face, a series of elongate field-grading electrodes which extend substantially parallel to the beam axis and are spaced apart between said plates, the number of electrodes in the two series being the same whereby corresponding electrodes in the two series form pairs, the paired electrodes being connected together so as to be at substantially equal potentials;

a resistive voltage divider connected between said plates, each pair of field-grading electrodes being connected to an intermediate point in said divider corresponding to the position of the pair with said series between said plates;

means for applying equal and opposite potentials to said plates, said potentials being substantially proportional to $\sqrt{(V/M)}$, thereby to provide, on the beam axis, an electric field of corresponding strength, which electric field is substantially perpendicular to both said magnetic field and the beam axis;

means for algebraically adding to each of said plate voltages a focussing component voltage which is substantially proportional to V , said focussing component voltages being equal and of the same polarity;

a second voltage divider, similar to said first divider, connected between the two resulting algebraic sum voltages; and

means for coupling corresponding points on the two voltage dividers thereby to provide, by means of the resulting potentials thereby applied to said field-grading electrodes, an electric field gradient across said beam, which gradient is proportional to V and is parallel to the electric field.

5. An ion accelerator comprising:

an ion source for providing ions of a selectable species having a mass M , said source including supplies providing probe, extraction and focussing potentials;

accelerating means associated with said source including a main accelerating potential supply;

means for energizing said accelerating means and said source supplies proportionately to form a beam of ions, including a substantial proportion of said selected species, having an energy V ;

magnet means, including a pair of pole faces lying on opposite sides of said beam, for providing a transverse magnetic field of predetermined intensity through which said beam passes;

a pair of electrostatic field-defining plates on opposite sides of said beam, between said pole faces;

means for applying equal and opposite potentials to said plates, said potentials being under analog control substantially proportional to $\sqrt{(V/M)}$, thereby to provide, on the beam axis, an electric field of corresponding strength, which electric field is substantially perpendicular to both said magnetic field and the beam axis and which balances the influence of the magnetic field on ions of the selected species of mass M at energy V .

6. An accelerator as set forth in claim 5 including analog control means for varying said extraction and focussing potentials in proportion to V .

7. An ion accelerator comprising:

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an ion source for providing ions of a selectable species having a mass M;
 accelerating means associated with said source;
 means for energizing said accelerating means to form a beam of ions, including a substantial proportion of said selected species, having an energy V;
 magnet means, including a pair of pole faces lying on opposite sides of said beam, for providing a transverse magnetic field of predetermined intensity through which said beam passes;
 a pair of plates on opposite sides of said beam, between said pole faces;
 adjacent each pole face, a series of elongate field-grading electrodes which extend substantially parallel to the beam axis and are spaced apart between said plates, the number of electrodes in the two series being the same whereby corresponding electrodes in the two series form pairs, the paired electrodes being connected together so as to be at substantially equal potentials;
 means for applying equal and opposite potentials to said plates, said potentials being substantially proportional to $\sqrt{V/M}$, thereby to provide, on the

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beam axis, an electric field of corresponding strength, which electric field is substantially perpendicular to both said magnetic field and the beam axis;
 means for dividing the voltage between said plates substantially in proportion to the spacings of said electrode pairs between said plates;
 means for algebraically adding to each of said plate voltages a focussing component voltage which is substantially proportional to V, said focussing component voltages being equal and of the same polarity;
 means for dividing the difference between the two resulting algebraic sum voltages; and
 means for applying to each pair of field grading electrodes a voltage which is a mixture of the corresponding voltage provided by said first voltage dividing means and the corresponding voltage provided by said second voltage dividing means, thereby to provide an electric field gradient across said beam, which gradient is proportional to V and is parallel to the electric field.

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