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METHOD AND APPARATUS FOR FORMING A FOCUSED MONOENERGETIC ION BEAM

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FIG. 1

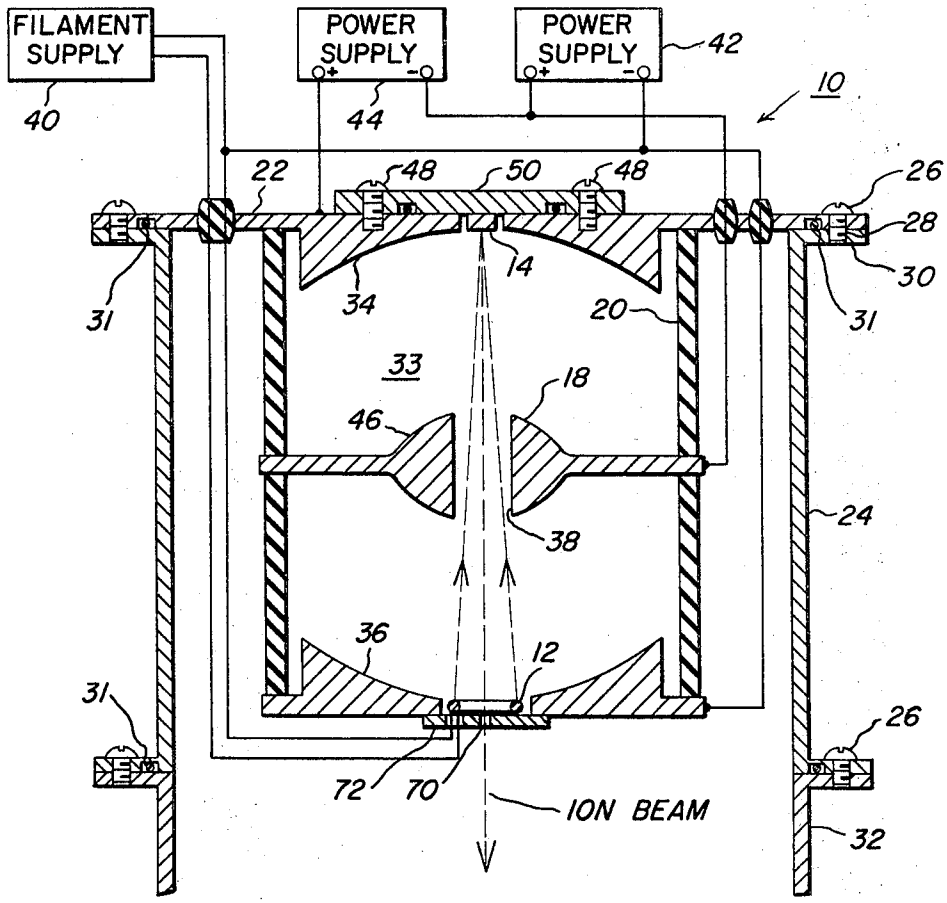
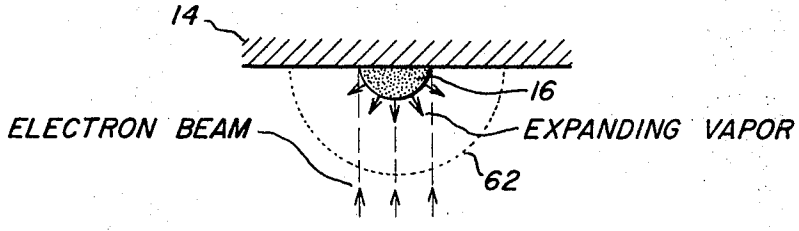



FIG. 2




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# METHOD AND APPARATUS FOR FORMING A FOCUSED MONOENERGETIC ION BEAM

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## ABSTRACT OF THE DISCLOSURE

A method and apparatus are described for producing a focused beam of monoenergetic ions from an electrically conducting source in the solid or liquid state by electron bombardment of the source to produce an ionized vapor cloud from which cloud the generated ions are extracted by a remotely positioned negative accelerating electrode. Focusing electrodes are provided proximate the ion source to focus the generated ion beam back along the axis of the electron beam and a common electrode is employed both to accelerate electrons to the ion source and to accelerate ions in the reverse direction. By focusing the beam to a relatively small diameter spot on the source, the ionized vapor cloud is small relative to the electrode spacing and the ion beam thus formed is essentially monoenergetic.

This invention relates to a method and an apparatus for the generation of a focused monoenergetic ion beam and in particular to the formation of a focused monoenergetic ion beam by positioning ion focusing means proximate a dense ion source while disposing a negative potential ion accelerating electrode at a remote location relative to the source.

Among techniques presently utilized in the formation of semiconductive devices are the ion implantation of a dopant into a semiconductive wafer, to produce asymmetrically conducting junctions at discrete locations in the wafer. Desirably the ion beam employed for implantation has a minimum divergence to permit focusing of the beam upon selected areas of the wafer and the depth of ion penetration into the wafer is a function of the energy level of the ions impinging upon the wafer surface.

Customarily, ion beams heretofore have been generated by the electron beam irradiation of solid or gaseous mediums to form an ionized cloud from which cloud the generated ions are extracted utilizing an ion accelerating electrode. However, when a gaseous medium serves as a source for a coaxial ion beam, ions are accelerated through a potential gradient in the cathode fall region between the plasma and the electron emitting cathode and, because the energy level of each ion is proportional to the potential gradient through which the ion is accelerated, the coaxial ion beams are characteristically broad spectrum energy beams. In those circumstances where ion generation has been achieved by electron beam irradiation of solids, e.g. those materials for which gaseous dispersions are difficult to obtain, the ion accelerating electrode generally has been positioned proximate the material to draw a majority of the generated ions from the source vapor. In this case also, substantial quantities of the generated ions are accelerated through widely differing voltage gradients and the ion beam is characterized by a broad spectrum energy level.

An additional problem encountered during the formation of an ion beam at a coaxial attitude relative to the ion generating electron beam is the tendency for the ion beam to become divergent due to the action of the electron beam focusing fields upon the ions. Similarly, when extensive ion focusing means are positioned between the ion source and the electron beam source, the fine focusing of the electron beam upon the surface of the ion source material is impaired thereby adversely affecting the formation of a monoenergetic ion beam.



It is therefore an object of this invention to provide an ion generator capable of producing a monoenergetic ion beam from a nongaseous source.

It is also an object of this invention to provide an ion generator having an ion focusing system producing an ion beam with a minimum divergence.

It is a further object of this invention to provide a novel method of simply forming a monoenergetic ion beam.

These and other objects of this invention generally are obtained by impinging an electron beam upon a solid source in sufficient intensity to vaporize and ionize a portion of the source, drawing the generated ions from the source vapor utilizing an initial ion accelerating field means disposed at a location remote from the source surface, e.g. at a span from the source preferably at least 50-fold the diameter of the electron beam upon the source, and focusing the generated ions intermediate the source and the initial accelerating field means to form a converging ion beam at the accelerating field means. Thus an ion generator in accordance with this invention would include means for generating an electron beam and means for focusing the electron beam upon the surface of an electrically conductive source material to vaporize a portion of the source. The vaporized material from the source then interacts with the electron beam to form positively charged ions and means are provided for forming an ion accelerating field to draw the generated ions from the source vapor in a substantially monoenergetic stream. Ion focusing means also are provided intermediate the ion source and the accelerating field means to form a convergent ion beam at the accelerating field means.

In a preferred embodiment of this invention, the ion beam and electron beam are coaxial and a common centrally apertured electrode is positioned intermediate the electron source and the ion source to serve as an accelerating electrode for ions and electrons passing therethrough. By disposing the ion focusing apparatus in the ion accelerating region to form a convergent ion beam at the aperture in the accelerating electrode, the ions have a high energy level entering the electron beam focusing region of the ion generator and a minimum divergence is produced as the high energy ion beam travels therethrough.

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, together with further objects and advantages thereof may best be understood by reference to the following description, taken in connection with the accompanying drawings, in which:

FIG. 1 is a simplified sectional view of an ion generator constructed in accordance with this invention, and

FIG. 2 is an enlarged pictorial illustration of the vapor cloud formed by electron beam impingement upon the ion source.

An ion generator **10** constructed in accordance with this invention is depicted in FIG. 1 and generally includes a filamentary cathode **12** for the generation of an electron beam which beam is focused upon solid metallic source **14** in sufficient intensity to vaporize a portion of the source thereby producing a high density vapor region **16** immediately adjacent the impinged surface of the source. Electron beam penetration into the vapor region produces an ionization of the vapor and the ions thus formed are withdrawn by accelerating electrode **18** centrally supported by insulating rods **20** intermediate cathode **12** and source **14** at a span from the source at least 50-fold the electron beam diameter upon the source to produce a monoenergetic ion beam (as will be more fully explained herein-

after). The entire structure is enclosed by a top plate **22** and a cylindrical sidewall **24** fixedly secured to the top plate by suitable means, such as screws **26** threadedly engaged in threaded bores **28** in flange **30**, with air leakage into the chamber being prevented by gaskets **31**. The lower end of the generator is secured to an ion utilization apparatus **32** e.g., an ion accelerator, and the interior of the ion generator is communicated with the vacuum system (not shown) of apparatus **32** to produce the desired subatmospheric pressure, e.g. $5\times10^{-5}$ torr. for optimum functioning of the electron source. In general, a vacuum less than $10^{-4}$ torr. is required for a spherical expansion of the vapor boiled off the surface of source **14** and a sharp decrease in vapor density with distance from the electron beam spot on the source. The continuous exhaust of ion generator **10** by the vacuum system of utilization apparatus **32** also inhibits the formation of a glow discharge throughout ion focusing chamber **33** of the ion generator as a result of the high potentials applied to the electrodes.

Although any nongaseous electron beam source can be employed for irradiation of source **14**, an electron gun having an annular filamentary cathode **12** and spherically shaped electron accelerating anode **18** is preferred because of the ability of the gun to inherently generate well focused electron beam at high power levels while providing a cathode aperture for the nondestructive passage of the generated ion beam therethrough. An electron focusing electrode **36** extends outwardly from cathode **12** in a generally spherical arc approximately concentric with the arcuate face of accelerating electrode **18** proximate the cathode to focus electrons emitted from the cathode through an aperture **38** within the accelerating electrode. Although electron focusing electrode **36** is preferably concentric relative to the accelerating electrode arc proximate the cathode to produce radial lines of force in the area between cathode **12** and accelerating electrode **18**, it is to be realized that minor modifications in accordance with well known techniques may be employed in the focusing electrode geometry, e.g. the focusing electrode may desirably have a smaller radius curvature or may have a shape which is conical rather than spherical dependent upon desired operating conditions, to compensate for space charge effects and to effect a convergence of the generated electrons in a small diameter upon source **14**. Similarly, when a high ion density from the generator is desired, cathode **12** can be designed as a spherical arc having a central aperture to permit the passage of generated ions into utilization apparatus **32**.

A suitable power supply **40** is serially connected to the filamentary cathode to provide energization therefor and one terminal of power supply **40** is connected to electron focusing electrode **36** to maintain the potential of the focusing electrode constant relative to the cathode potential. Alternatively, an additional power supply may be provided to produce a potential difference between electron source **12** and focusing electrode **36** to provide a fine focus control to correct for manufacturing tolerances. The potential of accelerating electrode **18** is fixed at a positive value relative to the cathode by a D.C. power supply **42** while a second D.C. power supply **44** connected in series additive relationship for power supply **42** serves to maintain source **14** positive relative to both accelerating electrode **18** and cathode **12**.

Accelerating electrode **18** fixedly positioned by insulating rods **20** approximately midway between cathode **12** and source **14** can be any conductive metal with molybdenum advantageously being employed when high potentials are employed to accelerate the electron beam from cathode **12**.

To assure a radial force focusing the generated electrons and formed ions into an axial position passing through accelerating electrode **18**, the center portion of accelerating electrode **18** is spherically shaped with the spherical arc **46** proximate source **14** being concentric with ion focusing electrode **34** while the spherical arc **48** of the accelerating electrode face proximate cathode **12** is concentric relative to the spherical arc of electron fousing electrode **36**. In general the sidewalls of aperture **38** within accelerating electrode **18** are parallel relative to the axis of the electron beam and the aperture has a diameter permitting passage of the electron beam therethrough without intercept.

Source **14** from which the ion stream is produced is situated at the geometric center of ion focusing electrode **34** which electrode has the general configuration of the electron focusing electrode **36** previously described, i.e. a spherical arc symmetrically disposed relative to the arc formed by electron focusing electrode **36**. The source itself is mounted upon a plate **50** fixedly secured to and electrically joined with the ion focusing electrode **34** surrounding the source by screws **48** to permit the convenient replacement or exchange of sources. Because of the generally symmetrical arrangement of ion focusing electrode **34** and electron focusing electrode **36**, ions formed by electron beam irradiation of source **14** are focused by electrode **34** along an axis coincident with the electron beam axis and the ion beam sequentially passes through the central apertures within accelerating electrode **18**, filamentary cathode **12** and an exit aperture **70** in plate **72** mounted on the face of the electron focusing electrode remote from source **14**. With source **14** lying at the geometric center of ion focusing electrode **34**, ions formed by electron beam irradiation of the source are focused immediately upon formation into a beam coaxial relative to the electron beam and few of the generated ions tend to diffuse throughout the chamber. Preferably, the arc of electrode **34** extends over a distance of at least 30% of the linear span between source **14** and electrode **18** to maximize the focusing of the ions over a substantial portion of their accelerated travel. In general, ion focusing electrode **34** directs the ions produced by irradiation of source **14** into a slightly convergent beam as the generated ions pass through aperture **38** thereby enabling the ion beam to be readily refocused to a fine spot or deflected with a minimum dispersion in the utilization apparatus while exit aperture **70** is situated at the focal point of ion focusing electrode **34** and desirably is of a diameter less than 3 fold the diameter of the electron beam upon source **14** to intercept ions of any undesired energy level.

Accelerating eletrode **18** is positioned at a distance at least 50-fold the diameter of the electron beam upon source **14** to produce a monoenergetic ion beam. Because the accelerating electrode ideally is positioned midway between the cathode and source to serve as an accelerating electrode both for ions and for electrons passing therethrough, the span between the focusing electrode and the filamentary cathode **12** preferably is at least 50-fold the diameter of the electron beam upon source **14**.

Varying operating conditions, e.g. the potential gradient between source **14** and accelerating electrode **18** and the diameter of the beam upon source **14**, can require a slight alteration in the geometry of the ion focusing electrode, e.g. the outer extremities of the focusing electrode may require a radius of curvature slightly shorter than a spherical arc, to assure that ions passing through aperture **38** are slightly convergent. Thus as the ions pass into the region between cathode **12** and accelerating electrode **18**, the divergence produced by electron focusing electrode **36** tends to compensate the slight convergence in the beam to produce a generally parallel beam exiting through the center of cathode **12**.

Source **14** is any solid or liquid electrically conductive material which is desirably ionized for a particular purpose. While the source can be in ingot form, a foil source supported upon a block of a material having a substantially higher evaporation temperature and a relatively lower thermal conductivity generally is preferred to limit heat loss through the source during operation. To inhibit contamination of the ion stream, e.g. by solid or gaseous

impurities in the source material, the foil source should be a high purity film preferably formed by vacuum melt techniques. Because the rod supports for accelerating electrode **18** provide an open structure, any occluded gases are exhausted rapidly by the vacuum system of the utilization apparatus.

As is illustrated more clearly in FIG. 2, the electron beam produced by cathode **12** is focused upon source **14** in an intensity to produce a vaporization of a portion of the source and the vapor diffuses outwardly in a generally hemispherically shaped vapor region **16** within the vacuum operating conditions of ion generator **10**. Hemispheric vapor region **16** characteristically has a radius approximately equal to the radius of the electron beam upon the surface of source **14** with the vapor density of the region being dependent upon the bombarding electron beam density and the vapor pressure of the evaporating source. Because the density of the vapor formed by the evaporating source decreases in the vacuum environment of the system as the square of the distance from the source, at a distance approximately 5 electron beam radii from the surface of source **14**, the density of the vapor cloud (and hence the ion formation rate) is reduced to approximately 4%. The total number of ions formed along the path of the electron beam is obtained by integrating the density as a function of distance with the result that the total ions generated beyond any radius decreases as the first power of radius. Thus 80% of the electron beam formed ions are located within an arc **62** having a radius approximately 5 fold the radius of the electron beam upon the target surface. By positioning the most proximate ion accelerating electrode **18** at a minimum distance of 50 fold the electron beam diameter upon source **14**, the ions formed within the relatively high density vapor hemisphere enclosed by arc **62** are accelerated through a voltage gradient which is at least 95% of the maximum. 80% of the ions generated therefore have an energy level not deviating by more than approximately 2.5% from the medium value. The remaining 20% of the ions of lower energy formed in the path of the electron beam beyond arc **62** are formed off axis because of the increasing width of the electron beam and are forward of the focal plane of focusing electrode **34** with the result that they are not focused on the exit aperture **70** and do not emerge from the structure. Hence 100% of the emergent beam consists of those ions formed within 5 electron beam radii from the surface of source **14** and have an energy spread of $\pm 2.5\%$ from the medium value.

What I claim as new and desire to secure by Letters Patent of the United States is:

**1.** An ion generator for producing a focused beam of monoenergetic ions comprising means for generating an electron beam, a source of electrically conductive material, means for focusing said electron beam upon the surface of said source material to vaporize and ionize a portion of said source material, means for forming an initial ion accelerating field to draw ions from said source vapor to said accelerating field means, and means for focusing said ions intermediate said source and said accelerating field means to form a converging ion beam at said initial ion accelerating field means, said ion focusing means and said electron focusing means being symmetrically disposed to form said ion and said electron beams along a coaxial path.

**2.** An ion generator according to claim **1** wherein said initial ion accelerating field is at a span from said electron impinged source surface at least 50-fold the diameter of said beam upon said source surface.

**3.** An ion generator according to claim **2** further including a plate positioned at the focal plane of said ion focusing means, said plate having an aperture coaxial with said ion beam and being of a diameter less than 3-fold the diameter of said electron beam upon said source.

**4.** An ion generator for producing a focused beam of monoenergetic ions comprising a cathode, a metallic target, means for energizing said cathode relative to said target to generate an electron beam therebetween, means for focusing said electron beam upon said target at a sufficient intensity to vaporize and ionize a portion of said metal target, and apertured electrode means for accelerating said ions generated by said electron beam, said apertured electrode means being circumferentially disposed about said electron beam and situated from said target at a span at least 50-fold the diameter of said electron beam upon said target to draw ions from said target vapor in a substantially monoenergetic stream.

**5.** An ion generator according to claim **4** further including an ion focusing electrode having the physical configuration of a spherical arc, said target being situated at the geometric center of said electrode.

**6.** A method of forming a focused beam of monoenergetic ions comprising impinging an electron beam upon a metallic source at a sufficient intensity to vaporize a portion of said source, said vaporized source interacting with said electron beam to form metallic ions, forming a negative potential field at a span from said metallic source surface at least 50-fold the diameter of said electron beam upon said source surface to draw ions from said source vapor to said negative potential field in a substantially monoenergetic stream, and focusing said ions intermediate said metallic source and said negative potential field to produce a slightly converging ion beam at said negative potential field.

**7.** A method of forming an electron beam according to claim **6** comprising intercepting ions of an undesired energy level upon an apertured plate positioned in the focal plane of said ion focusing means.


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250—41.9; 313—230