

United States Patent

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[54] **PROGRAMMED FINE ION IMPLANTATION BEAM SYSTEM**
7 Claims, 2 Drawing Figs.

[52] U.S. Cl. **250/49.5,**
 148/1.5, 313/63, 328/230
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 H01j 27/00, H01j 29/76
 [50] Field of Search 313/63, 63
 X; 250/49.5 O

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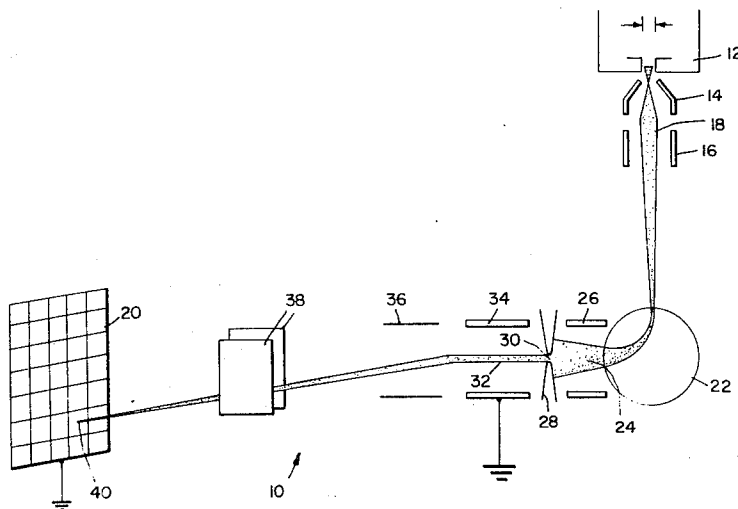
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ABSTRACT: A very small spot from an ion beam is effected
 by utilizing one or more apertured plates having a central hole
 through which only a small portion of the ion beam can pass.
 Decelerating electrodes may be placed before the aperture in
 order to lessen the energy of the ions sufficiently to preclude
 sputtering of the aperture.



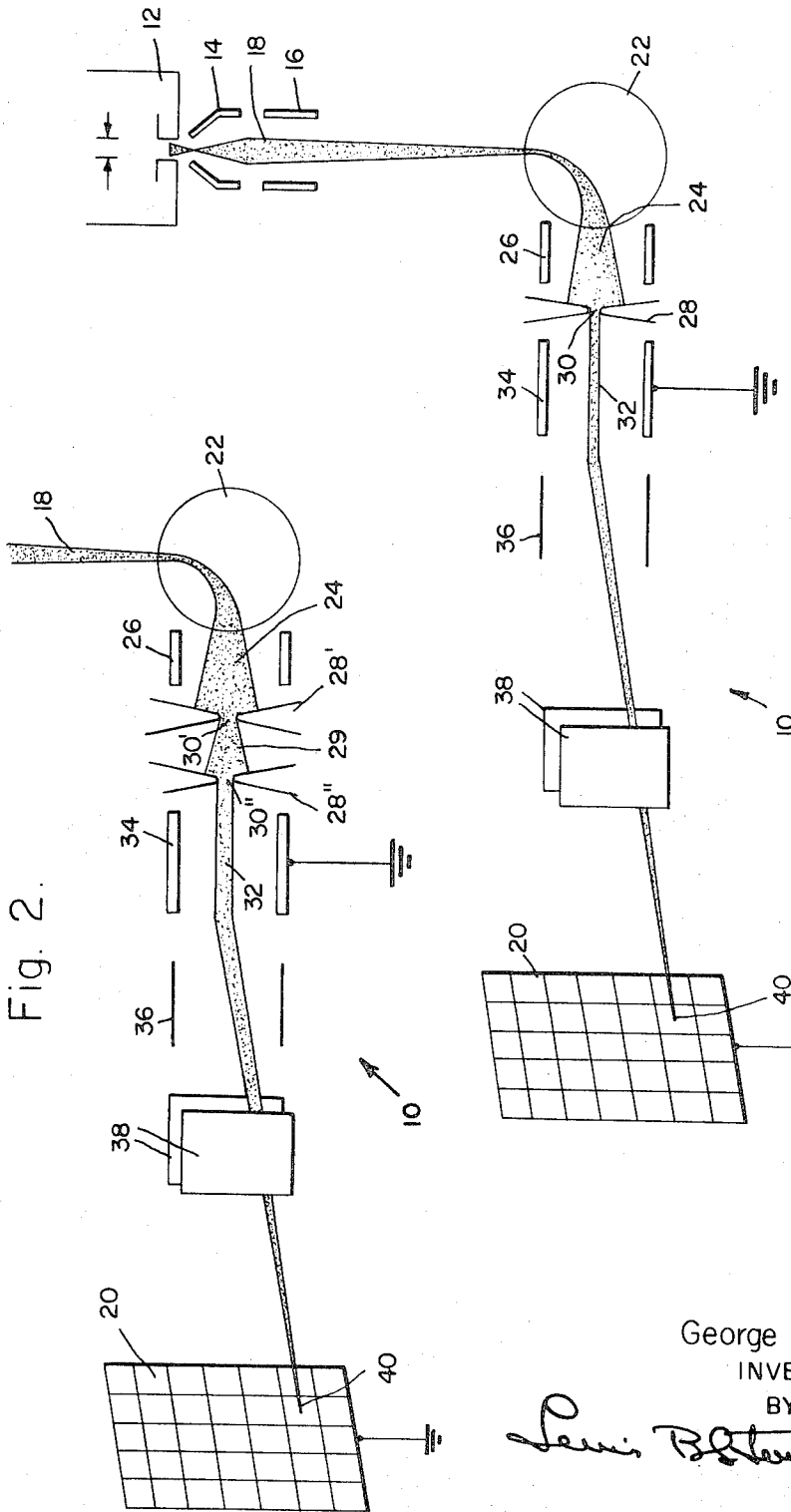


Fig. 1.

Fig. 2.

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PROGRAMMED FINE ION IMPLANTATION BEAM SYSTEM

The present invention relates to an ion implantation system and, more particularly, to such a system designed to produce a very small spot with sufficient current for programmed spot implantations in a specimen or target, such as a wafer of silicon or other substrate material, by means of a raster scan technique. Single or multiple implants may be effected by the system for a large scale integrated array of semiconductor devices.

Prior ion implantation methods have required the use of masking techniques to obtain a desired doped pattern in a substrate by flooding a target with ions from an ion beam. These prior methods have been effective to obtain a uniformly implanted or doped array of semiconductor devices; however, it has not heretofore been possible to obtain discretely implanted semiconductor devices at specified sites without the use of masking techniques. Such methods for applying masks are well known in the art and it is also well known that such techniques are expensive and time consuming. A related photolithographic technique has also been utilized; however, this technique is limited in resolution and, therefore, limits the size of devices obtainable.

In addition, it is necessary to provide prior ion beams with sufficient current density in order that proper implantation can be effected. Such current densities, however, are of such energy that they can cause sputtering of any materials upon which they impact, thereby necessitating frequent replacement thereof. In some cases, such sputtering cannot be tolerated, yet there has been no satisfactory means for overcoming this problem.

Furthermore, when ions are extracted from a source, the beam is invariably not perfectly collimated, that is, the beams do not emanate from the source in parallel paths. One of the causes of this nonparallelism of the ion beam is a transverse spread caused by mass separation. Another cause is the transverse thermal velocity of the extracted ions, wherein the velocities of the extracted ions are not all the same and wherein their paths are not parallel. In order to focus the ions into a comparatively parallel or convergent condition along a specified path, focusing lenses are utilized. However, such lenses must be very carefully designed and fabricated and placed within the ion implantation system.

The present invention is directed to the production of a fine ion implantation beam for programmed local implantations by means of a very small spot. In order to obtain such a spot, for example, of approximately 1-micron diameter, the beam must be limited in such a manner that the convergence angle is held within an angle which is no greater than approximately 0.02 radians. To obtain such a narrow beam having the required convergence angle in the presence of transverse thermal velocities, one or more limiting apertures must be utilized. One such aperture comprises a disc with a very small hole therein so that only a very small portion of the ion beam may pass therethrough. This small portion of the beam is located along the axis of the beam path and the aperture is so designed as to reject a large portion of those ions having transverse thermal velocities which are not close to the desired narrow beam axis.

In order to prevent sputtering of the aperture by the large portion of rejected ions, one embodiment of the invention utilized a means by which all ions are sufficiently decelerated so that their energy is less than that at which sputtering would occur. This deceleration is effected by the use of electrodes having a potential which is close to that of the source. After the desired ions have passed through the limiting aperture, they are focused, accelerated, and subsequently deflected in orthogonal directions so as to precisely position the beam for programmed impact upon the target.

In another embodiment, the ion beam is not decelerated at the aperture and the sputtering thereof by the high energy beam is tolerated. This condition shortens the life of the aperture but may be preferred in some circumstances.

In order to obtain the desired spot implantation of approximately one micron, a current of the order of 10^{19} amperes is required at the target which, in turn, requires a source current density of approximately 2 ma./cm.² or greater of the desired dopant ion, for example, phosphorous or boron. The value of required source current density must be sufficiently high because, in order to focus the beam having transverse thermal velocities into a fine spot, it is necessary to provide an initial high current density and then shear off most of the current. Such sources providing the desired initial high current densities include duoplasmatrons, surface ionization sources, and electron bombardment sources.

After the desired dopant ion has been extracted from the source and initially focused, it may be passed through a magnetic mass separator which is so adjusted as to cause the beam to be slightly divergent at exit. The system of the present invention, however, can also be used without mass separation to avoid the further beam spread caused by the mass separator beyond the spread in initial energy of the ions in the source. In such a case, a surface ionization source is desired since this type source yields a very uniform initial energy. Regardless of whether mass separation is utilized, the beam is then decelerated and collected on an electrode having a potential which has a value near that of the source potential and within the sputtering threshold of a limiting aperture.

A small fraction of the beam passes through the limiting aperture and thereafter is accelerated by an electrode, deflected electrostatically, and finally focused. If greater control of the ion beam is required in order to further limit the number of ions passing along the desired beam axis and/or to provide a precise mechanical alignment of the selected ion beam independent of the mass separation, it may be desirable to use more than one limiting aperture.

It is, therefore, an object of the present invention to provide an ion implantation system designed to produce a very small ion beam spot to allow programmed spot implantation.

Another object of the present invention is the provision of a method for producing a very small ion beam spot for programmed spot implantations.

Another object is to provide a means and method for obtaining a very narrow ion beam with minimum sputtering of electrodes.

Other aims and objects, as well as a more complete understanding of the present invention, will appear from the following explanation of exemplary embodiments and the accompanying drawings thereof, in which:

FIG. 1 is a schematic view of the apparatus used to provide a narrow ion beam for spot implantation of a target by means of a single limiting aperture, and

FIG. 2 is a schematic diagram of an apparatus similar to that of FIG. 1 but utilizing two limiting apertures.

Accordingly, with reference to FIG. 1, a fine ion implantation beam system 10 comprises an ion source 12 having an extraction electrode 14 and focusing electrode 16 to produce an ion beam 18 of sufficient current density to permit spot implantations of a target 20 which may comprise one or more semiconductor devices arranged individually, as an array, as an integrated circuit, or as any other suitable device or material into which the ions are to be implanted. The beam is directed toward mass separator 22 which is designed to select the desired ion species by bending the beam through a desired angle. Separator 22 can be adjusted so that the beam is divergent as shown by indicia 24 at exit from the mass separator.

The beam thereupon, in an embodiment of the present invention, passes between a pair of electrodes 26 which define, with plate 28, the deceleration field region for divergent beam 24. At this point, the beam enters upon a limiting aperture plate 28, which may comprise, for example, tungsten or molybdenum. The limiting aperture is provided with a very small hole 30 in order to permit only those ions having the desired low transverse velocities to pass therethrough and along the desired axis. Thereafter, a narrow beam 32, as produced by aperture 30, passes within a focusing lens 34 in order to properly shape beam 32. Thereafter, the narrow

beam passes through a deflection system comprising vertical deflecting electrodes 36 and horizontal deflecting electrodes 38, both of which are placed on either side of the ion beam.

If desired, a double deflection system as disclosed in copending Pat. application Ser. No. 765,125, filed Oct. 4, 1968; now U.S. Pat. No. 3,569,757, granted Mar. 9, 1971, herewith may be used when accurate alignment of the beam and the substrate at all parts of the substrate is required. The beam finally impacts upon target 20 at a programmed spot 40 on one device in order to provide the desired spot implantation. Two-dimensional movement of the beam provides for localized implantations as desired.

Referring now to FIG. 2, a double limiting aperture 28' and 28'' having holes 30' and 30'' is used to further limit divergent exit beam 24. Beam 18, after passing through mass separator 22, and made slightly divergent at 24, is first passed through aperture 28' to produce a subsequent beam configuration 29. Beam 29 may still have more than the desired level of transverse velocities which are near the axis of the beam. Therefore, a second limiting aperture 28'' further limits the number of ions of beam 29 intended to pass along the desired axis to more precisely form narrow beam 32 than accomplished by the similar narrow beam of FIG. 1. The use of two limiting apertures also permits the direction of the limited ions to be mechanically defined, independent of any mass separation. In other respects, the system of FIG. 2 is the same as that of FIG. 1.

Acceleration means for both FIGS. 1 and 2 may be provided either between electrode 16 and mass separator 22 or between electrodes 38 and target 20. The limiting apertures and systems design disclosed herein can be used with other forms of mass separation, such as a Wien filter (E×B) separator. The incident ions will also possess a spread in energy and this energy spread will be transformed by the mass separator into a transverse velocity distribution. It is a purpose of the apertures to discriminate against these ions having high transverse velocity at exit from mass separation due to initial energy spread as well as those which left the source with transverse thermal velocities.

The function of source 12 is to produce an ion beam of sufficiently high current density as to produce the fine or narrow beam 32 since most of the current is sheared off by aperture 30. Such sources comprise duoplasmatrons, surface ionization sources, and electron bombardment sources, among others.

The duoplasmatron employs an axial electron current flowing from a cathode to an anode in which there is an aperture opening into an expansion cup. A plasma column is formed and constricted by a strong electric field from an intermediate electrode and by a magnetic field which is inhomogenous, that is, it diverges in the downstream direction. The plasma expands through the anode aperture where the ion beam is extracted by a truncated conical electrode.

In the surface ionization source, the vapor of the species to be ionized is directed into a high work function surface which captures the least bound electron. Ions and atoms are thermally desorbed by maintaining the ionizing surface hot, in the region of 1,000° K. to 2,000° K., the ions being extracted and focused into a beam by the application of the positive electric field.

The electron bombardment-type ion source comprises a chamber into which electrons are introduced at one end thereof by an electron emitter. The electrons are caused to move axially with a reciprocating motion and are confined to prevent radial expansion by the use of an axial magnetic field. The gas to be ionized is also introduced into the chamber and the atoms are ionized by impact by the electrons. The chamber therefore fills with a plasma and the ions are extracted from the chamber by application of a negative extraction field through holes at another chamber end.

Mass separator 22, as stated above, functions to separate out unwanted ion species and select the desired ion species. In order to accomplish this purpose, the mass separator can comprise a pair of large electromagnets placed about a beam con-

duit having a predetermined curve. In order to accomplish the function of mass separation, the magnetic field intensity of the magnets is changed or the angle of the conduit is changed. Both these parameters depend upon the energy of the incident ion beam which, in turn, primarily depends on the potentials of source 12 and extraction electrodes 14. The ion beam approaching the mass separator has a specific energy in terms of its momentum and, since each ion species has a different mass, the momentum of all ions included within the beam, including the undesired beams, have particular values of momentum. By adjusting the magnetic field intensity of the magnets and by providing the conduit with a particular angle, only those desired ions having a particular momentum will be bent through the angle for supply to limiting aperture 28. All undesired ion species will either make too great or too small a bend at the angle and, consequently, will impact upon the sides of the conduit. Damage from impact of ions into aperture plate 28 away from aperture 30 is limited by making the aperture plate of such potential that a deceleration field region is set up between the deceleration reference electrode 26 and the aperture plate 28.

The angle of deflection is dependent upon the magnetic field intensity and the energy of the incident ion beam, and this angle may be measured in terms of the mass of the ion, m , and the integral multiples of electron charge, g , as the ratio m/g . If this value is large, the deflection angle is small and, conversely, if the value is small, the deflection angle is large. Therefore, by adjusting the m/g value to that of the desired ion species, only that species will be bent about the desired angle.

Mass separator 22 may be further shaped so that the magnetic field will affect the ion beam upon entrance and exit equally across the cross section of the beam. Furthermore, the mass separator can be so constructed that the exiting ion beam will be slightly divergent in order to assist in separating out ions with high transverse velocities.

As stated above, the deceleration region is established between electrodes 26 and aperture plate 28 which is at a potential which is near to and negative with respect to source 12. The respective values of the source, the extractor electrodes, focusing lens 16, the deceleration electrodes, and the limiting aperture are adjusted to obtain maximum control of the ion beam. For example, if the source were at a potential of 50 kv., the extractor electrodes could be at a 40-kv. potential, the focusing at a 30-kv. potential, the deceleration reference electrodes 26 at a 30-kv. potential, and the limiting aperture plate 28 at slightly less than the source potential, such as 49.95 kv. In this system, the remaining elements of the system, focusing and accelerating lens 34, deflection electrodes 36 and 38, and target 20 would be at ground. With such a system, a small fraction of the beam, approximately 10^{15} , passes through one or more tiny limiting apertures.

The above arrangement may be modified; for example, source 12 may be at ground and target 20 at a high potential. In either case, the final deflection of the beam must be very precisely controlled. It may not be possible to obtain the desired precision if the deflection amplifier is 50 kv. or greater below ground. Also, in order to avoid precision regulation of the magnet current of the separator 22, it may be necessary to limit the beam by two apertures, as shown in FIG. 2, so that the slope of the ions passing through the limiting aperture does not depend on the magnetic field.

Although the invention has been described with reference to particular embodiments thereof, it should be realized that various changes and modifications may be made therein without departing from the spirit and scope of the invention.

We claim:

1. An ion beam device for producing an ion beam suitable for ion implantation of a target, said ion beam device comprising:

means for producing an ion beam, said means for producing an ion beam comprising an ion source, an extraction electrode for extracting ions from said ion source, and a focusing electrode for focusing the extracted ions into a beam;

5

mass separation means positioned along the ion beam for separating out of the ion beam ions of other than the selected species by deflecting the unselected species away from the beam path;

an aperture plate and decelerating field reference electrode means positioned downstream along the beam path from said mass separation means for decelerating the ion beam to reduce the energy of the beam to minimize sputtering from beam impingement on said aperture plate, said decelerating field reference electrode being positioned between said aperture plate and said mass separation means and being at a potential substantially less positive than the potential of said ion source, said aperture plate being substantially at the potential of said ion source, said aperture plate having a limiting aperture therein positioned along the path of the beam, said limiting aperture being of smaller size than the beam so that only a portion of the beam is able to pass therethrough and the balance of the beam impinging the aperture plate is of sufficiently low energy that it reduces sputtering of the aperture plate; and focusing lens electrode positioned downstream of said limiting aperture so that the ions passing through said limiting aperture are focused for a minimum spot size on the target and are accelerated towards the target; deflecting electrodes positioned adjacent the ion beam downstream of said accelerating and focusing lens electrode to deflect the ion beam onto a target.

2. The ion beam device of claim 1 wherein horizontal and vertical deflecting electrodes are positioned alongside of the ion beam downstream of said accelerating and focusing lens electrode so as to deflect the accelerated and focused beam onto the target.

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3. The ion beam device of claim 2 wherein said limiting aperture comprises a single limiting aperture.

4. The ion beam device of claim 2 wherein said limiting aperture comprises first and second serially positioned limiting apertures, said first and second serially positioned limiting apertures being arranged along the path of the ion beam so that a portion of the ion beam which is passed by said first limiting aperture is stopped by the material surrounding said second limiting aperture so that the number of ions passing along the ion beam is twice reduced.

5. The ion beam device of claim 1 wherein said ion source is arranged to be held at a positive potential with respect to the target, and said extraction electrode is arranged to be held at a positive potential with respect to said target less than the potential of said ion source, said decelerating field reference electrode means is arranged to be held at a field reference potential with respect to said beam and said limiting aperture is arranged to be held at a positive potential with respect to said target which is of a value between the potential of said ion source and the potential of said extraction electrode.

6. The ion beam device of claim 5 wherein said limiting aperture comprises a single limiting aperture.

7. The ion beam device of claim 5 wherein said limiting aperture comprises first and second serially positioned limiting apertures, said first and second serially positioned limiting apertures being arranged along the path of the ion beam so that a portion of the ion beam which is passed by said first limiting aperture is stopped by the material surrounding said second limiting aperture so that the number of ions passing along the ion beam is twice reduced.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,585,397 Dated June 15, 1971

Inventor(s) George R. Brewer

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 2, line 2 - " 10^{19} " should be " 10^{-9} ".
Page 4, line 13

Col. 2, line 69 - "slate" should be "plate".
Page 6, line 26

Col. 4, line 51 - " 10^{15} " should be " 10^{-5} ".
Page 11, line 12

Signed and sealed this 10th day of October 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents