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(72) Inventors: John Lawrence Forneris, William Wallace Hicks, John Howard Keller, Charles Michael McKenna, James Anthony Siermarco, Wolfgang Friedrich Mueller.

(54) ION IMPLANTATION APPARATUS

(71) We, INTERNATIONAL BUSINESS MACHINES CORPORATION, a Corporation organized and existing under the laws of the State of New York in the United States of America, of Armonk, New York 10504, United States of America do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:–

The present invention relates to ion bombardment or implantation apparatus.

Ion implantation is a technology of rapidly increasing importance in the fabrication of integrated circuits, particularly bipolar integrated circuits. In bipolar technology there is an increasing demand for (1) high dosage but relatively short time cycle implantation operations, and (2) ion implantation technology useful for introducing impurities through openings having at least one lateral dimension no greater than one mil. Since the implantation dosage is dependent on the combination of current and time, it follows that in order to achieve a high dosage in a relatively short time, the technology must move in the direction of high current ion implantation beams having currents greater than 0.5 ma. It has been found that when making such high current ion implantations of conductivity-determining impurities through electrically insulating layer openings having dimensions of the order of 0.1 to 1 mil. as is required in high density, large scale integrated circuits, there is a substantial tendency toward the impairment or destruction of portions of this electrically insulating layer as well as exposed semiconductor areas resulting in potential short circuits which render the integrated circuit inoperative.

We believe that such impairment or destruction occurs due to an electrical breakdown of a potential built up on the insulating layer arising from the charge deposited by the positive ions which make up the primary ion beam. This potential buildup is particularly pronounced in high current beams which have a high density of positive ions. Without being bound on the theory involved, we believe that in such high current beams, positive ions have such a high density that the floating cloud of electrons, which is inherently produced through the operation of the ion bombardment apparatus such as through secondary electron emission from material struck by the ion beam and neutral background gas ionization by the ion beam, is sufficient in quantity to fully neutralize the charge created by the positive ions on the target.

The concept of the positive ion beam and the effect of the secondary electron cloud is discussed in some detail in U. S. Patents 3 ,997,846, 4,011,499 and 4,013,891, and in the article, "High Current Electron Scanning Method for Ion Beam Writing", W. C. Ko, at pp. 1832 - 1835, IBM Technical Disclosure Bulletin, Vol. 18, No. 6, November 1975, as well as in the text, "Ion Beams With Application to Ion Implantation", R. G. Wilson and G. R. Brewer, (John Wiley & Sons, New York, 1973) at pp. 132 - 143.

In addition, it appears that when the openings through which the ions are to be implanted have small lateral dimensions of the order of 1 mil. or less, secondary electrons which are normally produced by positive ions striking the semi-conductor substrate are reduced; this further contributes to the deficiency of available secondary electrons at the surface to neutralize the positive ion accumulation to prevent charge buildup. This effect is discussed in detail in copending application No. 00570/78 (Serial No. 1,549,971).

While the problem described will arise in connection with ion implantation through minute openings, similar problems may be expected to arise when the ion implantation is conducted with high current beams through thin regions in an electrically insulating layer over a semiconductor substrate rather than through openings in such an insulating layer.

The prior art has a suggested solution to this problem of charge buildup which involves directly irradiating the surface of the electrically insulating material with electrons in sufficient quantity to produce a negative potential on the surface of the insulating material sufficient to offset any positive charge produced by the ions in the beam. We have found that when such a direct impingement method is used, undesirable effects are produced. First, the electron source is usually a heated filament, such as a metallic member of some sort, or a plasma. Such an electron source can be adversely affected by material emitted from the target during ion bombardment and, in addition, these sources can give off material which can contaminate the target. In addition, since the electron source is conventionally a heated member such as a heated filament, the heat from the source will produce an undesirable heating effect at the target. Thus, if the target comprises a covering of an electrically insulating material such as photoresist which is affected by heat, then the heated filament may damage the target.

In addition, since ion beam dosimetry, i.e., the measurement and control of ion beam current, is considered to be significant in ion implantation apparatus, there is the need in the art, particularly with high current beams, for a method and apparatus for controlling and minimizing the positive surface potential of the target which is compatible with dosimetry apparatus for measuring the beam current.

According to the present invention there is provided an apparatus for bombarding a target with a beam of ions including an arrangement for measuring the ion beam current and controlling the surface potential of the target, the arrangement comprising a Faraday cage formed at least in part by the target and by walls adjacent to and electrically insulated from the target and surrounding the beam, at least one electron source for supplying electrons to the interior of the Faraday cage, means within the cage for blocking direct rectilinear radiation from the source to the target, means for measuring the target current, means for combining and measuring the target and the wall currents to provide a measurement of the ion beam current, and means for varying the quantity of electrons supplied to the interior of the cage to control the target current and thereby the target surface potential.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of an ion implantation apparatus according to the present invention,

Figure 1A is an enlargement of the arrangement enclosed by the dashed lines in Figure 1.

Figure 2 is a partial sectional view of a modification of the arrangement of Figure 1A,

Figure 3A is a fragmentary front view of a further arrangement which may be used in place of that shown in Figure 1A, and

Figure 3B is a partial sectional view of the arrangement of Figure 3A taken along lines 3B - 3B.

Referring now to the drawings and initially to Figure 1, a structure for measuring the ion beam current and controlling the surface potential of the target is shown within the dashed lines 10, and forms part of an otherwise conventional ion implantation apparatus. It should be recognized that the remainder of the apparatus in Figure 1 outside the box 10 is schematic in nature and represents a conventional ion implantation apparatus such as that described in U. S. Patent No. 3,756,862. The apparatus in Figure 1 includes a conventional ion source 12 which may be any suitable high density source, although in the embodiments illustrated a hot filament electron impact source is shown adapted to be operated in an oscillating electron discharge mode. An ion beam is extracted from the source in the conventional manner through an extraction electrode 16 via an aperture 15. Electrode 16 which is also known as an accel-electrode is maintained at a negative potential by the decel supply. A source electrode 17 is maintained at a positive potential with respect to filament 12 by the anode supply. A decel-electrode 18 is also provided, maintained at ground potential. It should be recognized that the bias voltages described may be varied in the operations of the device by those skilled in the art.

The beam extracted from the ion source by the electrode arrangement disclosed is transmitted along a beam path generally indicated at 19 to an analyzing magnet 20 of conventional design. The beam is further defined in the conventional manner by apertured plates 21 and 22 located on either side of the analyzing magnet. A conventional beam defining aperture 24 is included in the apparatus as illustrated. Then, the beam is further defined by aperture 26 formed in plates 25 and strikes target 30.

Now, to describe the structure which permits the control of the surface potential of the target while measuring the ion beam current, reference is made to the structure shown diagrammatically within dashed line box 10 which is enlarged in Figure 1A. The structure is a modified Faraday Cage structure of the type described in U. S. Patent 4,011,449 used to measure the beam current. Target 30 combines with side walls 27 and rear walls 28 to form a Faraday Cage structure substantially surrounding ion beam 29. Target 30 comprises a semiconductor wafer holder 23 supporting a plurality of wafers 31. The wafer holder 23 is rotated and oscillated in the directions indicated by arrows by a standard deflection apparatus such as that described in U. S. Patent No. 3,778,626 in order to ensure uniform distribution of the ion beam 29 across the surfaces of all of the wafers 31 mounted on the target support 23. Alternatively, of course, the Faraday Cage arrangement may function with a stationary target 30. The Faraday Cage including the target is enclosed in any suitable conventional chamber (not shown) for maintaining a high vacuum in the ion implantation apparatus.

The side walls 27 must be electrically insulated from target 30. In the present embodiment it is shown spaced from target 30. Side walls 27 are biased at a more negative potential than the potential being applied to the target 30. In the embodiment shown, target 30 is biased at ground through connector 32 and walls 27 are biased more negatively with respect to ground by supply V_W. Electron sources 33 and 33' are conventional electron sources designed to introduce variable quantities of electrons 34 into ion beam 29 in order to have a sufficient quantity of electrons in the region of the ion beam to neutralize any charge buildup which may result in an undesirable positive potential formed at the surface of a wafer 31 being implanted. The problem of such an undesirable charge buildup, particularly when high current ion beams are used to bombard or implant semiconductor wafers through insulating layers having only minute openings or no openings at all, has been discussed above. Electron sources 33 and 33' may be any conventional source of electrons such as a heated filament which emits electrons. Alternatively, they may be conventional plasma bridges, electron guns with or without magnetic fields or field emission electrodes. The electron source filaments 35 are supplied by a conventional power supply, not shown, which may be varied to increase or decrease the current through the filaments 35 and thereby to increase or decrease the electrons 34 which are being emitted into the path of ion beam 29. Each filament is preferably biased by voltage V_F to a negative level with respect to side walls 27. It is important each electron source 33 and 33' be set into recesses formed in side walls 27 to such an extent that there is no rectilinear or line-of-sight path connecting any part of the respective filament to any part of the wafer; the wall portions 36 of walls 27 act to shield against such a path.

Rear wall 28 is separated from side wall 27 by a layer of electrically insulating material 37. Voltage supply V_P serves to bias the rear wall 28 as the most negative with respect to side walls 27 and filament 35. With the biasing arrangement shown, the electrons 34 introduced into the beam as well as the secondary electron cloud which accompanies the ion beam are contained within the Faraday Cage formed by rear walls 28, side walls 27 and target 30, and are moved away from the walls in the direction toward the target. The following are some typical operating parameters. When using apparatus operating at an energy level of the order of 50 Kev. with ions such as arsenic, and a beam current of the order of 0.5 ma. or higher, good results are achieved by maintaining the target at ground potential, a bias on side walls 27 of about -50 volts, a bias on the filaments 35 of about -60 to -100 volts, and a bias on rear wall 28 of -200 volts. The beam current measurement is determined by combining the current from all of the elements, i.e., the current from target 23, from side walls 27 and from rear wall 28 at ammeter 38 to provide a reading of the beam current in a manner similar to that described in U. S. Patent 4,011,449. At the same time, the target current alone may be monitored through ammeter 39 to provide a reading of the target current which permits the adjustment of the amount of electrons 34 being introduced into the beam 29 from filament 35.

In order to prevent a buildup of a positive potential on any insulating layer formed on the surface of a target wafer 31, it is desirable that the target current be either at zero or negative to some extent.

In the structure of Figure 1A, the function of rear wall 28 which is biased at the most negative level in the Faraday Cage is to ensure that a minimum of the electrons will leave the Faraday Cage from the rear of the cage. In a modified embodiment of this structure as shown in Figure 2, rear wall 28 may be eliminated and a magnetic field 40 perpendicular to the ion beam may be created by a pair of magnets 41 and 42. This field will substantially prevent any rearward movement of the electrons associated with ion beam 26 by functioning in the conventional manner as an electron barrier.

With ion beams implanting certain dopants such as arsenic which evaporate readily under operating temperatures, a problem may arise due to the precipitation of evaporated arsenic on the target. In the standard operation of ion implantation equipment, any arsenic which is evaporated during the operations would precipitate on the walls of the Faraday Cage adjacent to the target. However, where as is the case with the present structure, electrons are being provided to the ion beam from a heated source such as filament 35 which operates at a temperature of the order of from 1500° to 2700° C, the walls 27 and particularly the shield portions 36 thereof become quite hot. Because the walls and shield are at a higher temperature than the target, any arsenic vapor tends to deposit on the target wafer surface. This distorts the processing and particularly the arsenic doping level measured from the implantation of arsenic. This occurs because the evaporated arsenic is not in the ionic state and consequently, is not measured by the dosimetry apparatus during the implantation stage. However, since it is deposited on the wafer surface, it is driven into the wafer during subsequent high heat processing stages of the wafer. Consequently, quantities of arsenic which are not accounted for by the ion implantation dosimetry end up in the wafer and thereby potentially will distort the desired implantation dosages and dopant concentration levels in the wafer.

In addition, arsenic which may have been plated on to the structure walls during a previous implantation cycle may be evaporated from the walls during a subsequent implantation cycle to adversely affect the dosimetry in the subsequent cycle.

Accordingly, the structure of the embodiment shown in Figure 1A is modified to avoid this effect as shown in Figure 3B which is a sectional view taken along lines 3B - 3B of Figure 3A. Figure 3A is a front view of the apparatus looking from the target towards the beam along the axis thereof. Because much of the apparatus in Figures 3A and 3B is substantially the same as that shown in Figures 1 and 1A, for convenience in illustration and description the elements in Figures 3A and 3B which are equivalent to elements in Figures 1 and 1A will be designated with the same numbers as the elements in Figures 1 and 1A preceded by the digit "1", e.g., side wall 27 in Figure 1A is equivalent to side wall 127 in Figures 3A and 3B. Thus, when an element in Figures 3A and 3B is mentioned which is the equivalent of an element in Figures 1 and 1A no further description will be made and it will be assumed that it operates in the same manner as in the original structure. In Figures 3A and 3B, wafers 131 are being implanted with an ion beam 129. The wafers are mounted on a wafer holder 123 of the target 130. Side walls 127 are modified to contain cooling conduits 150 which are connected to an input conduit 151 through which fluid enters the cooling system and an output conduit 152 through which fluid leaves the cooling system. A coolant such as compressed air or fluorocarbon coolant may be passed through the conduits to cool walls 127 and particularly shielding portions 136 thereof to maintain these walls at a temperature below that of the target irrespective of the temperature of filaments 135 which introduce electrons 134 into the ion beam 129. The coolants used must be electrically insulating in character so that they do not affect the dosimetry, i.e., the ion beam measurement operation of the apparatus. Likewise, the external portions of the cooling system should be electrically insulated from the walls of the Faraday Cage. As shown in Figure 3A, connectors 153 are made of electrically insulating material and act to insulate conduits 151 and 152 from walls 127.

In Figure 3A, a section is broken away to show the disposition of one of the filaments 135 of electron source 133 with respect to beam 129. In all other respects, the elements of Figures 3A and 3B function in substantially the same manner as their equivalent elements in Figures 1 and 1A. Further, the cooled beam-current-measuring and surface-potential-controlling apparatus shown in Figures 3A and 3B is used in combination with conventional ion implantation apparatus, the remainder of which is diagrammatically shown in Figure 1.

With the cooling apparatus described, when the filament is heated to temperatures of the order of 1500° to 2700° C, the walls 136 may be maintained at less than 100° C during ion beam operation, while the target which is heated mainly by the ion beam reaches a higher temperature of about 150° C.

WHAT WE CLAIM IS:-

1. An apparatus for bombarding a target with a beam of ions including an arrangement for measuring the ion beam current and controlling the surface potential of the target, the arrangement comprising a Faraday cage formed at least in part by the target and by walls adjacent to and electrically insulated from the target and surrounding the beam, at least one electron source for supplying electrons to the interior of the Faraday cage, means within the cage for blocking direct rectilinear radiation from the source of the target, means for measuring the target and the wall currents to provide a measurement of the ion beam current, and means for varying the quantity of electrons supplied to the interior of the cage to control the target current and thereby the target surface potential.

2. The apparatus of Claim 1, including means for biasing the walls at a negative potential with respect to the target.

3. The apparatus of Claim 2, wherein the Faraday cage has a rear wall defining an opening along the axis of the ion beam opposite to the target through which the ion beam enters the Faraday cage, and side walls between the rear wall and the target, the rear wall being electrically insulated from the side walls and the arrangement further including means for biasing the rear wall at a negative potential with respect to the side walls.

4. The apparatus of Claim 2, wherein the Faraday cage has side walls having an opening along the beam axis by which the ion beam enters the Faraday cage and impinges upon the target, and means adjacent the opening on the opposite side of the side walls to the target for providing a magnetic field perpendicular to the ion beam.

5. The apparatus of Claim 3 or 4, wherein the electron source is a heated filament located in a recess in the side wall, whereby a portion of the side walls serves to block the direct radiation.

6. The apparatus of Claim 5 in dependence upon Claim 3, further including means for biasing the filament at a potential which is positive with respect to the rear wall and negative with respect to the side walls.

7. An apparatus according to any preceding claim, further comprising means for cooling the blocking means to a temperature below that of the target.

8. An apparatus substantially as described with reference to Figures 1 and 1A, 2 or 3A and 3B of the accompanying drawings.

J.P. RICHARDS
Chartered Patent Agent,
Agent for the Applicants.

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1584224 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

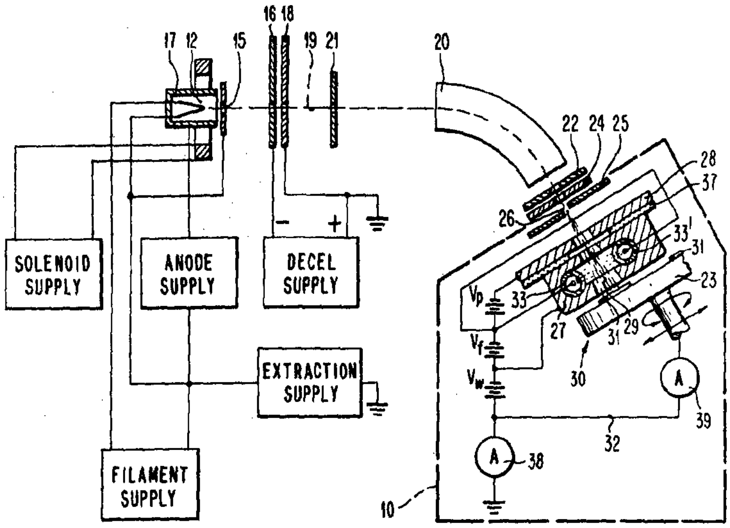

FIG. 1

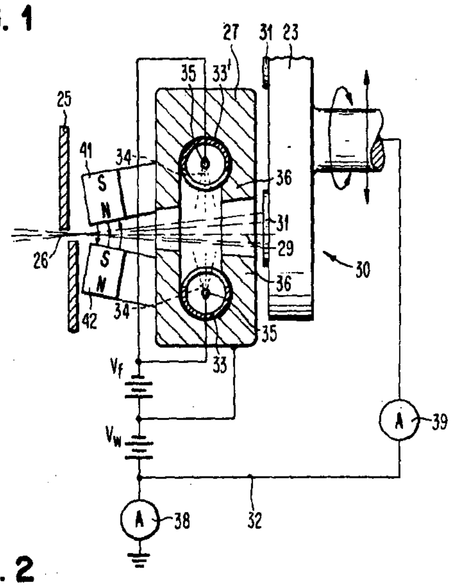

FIG. 2

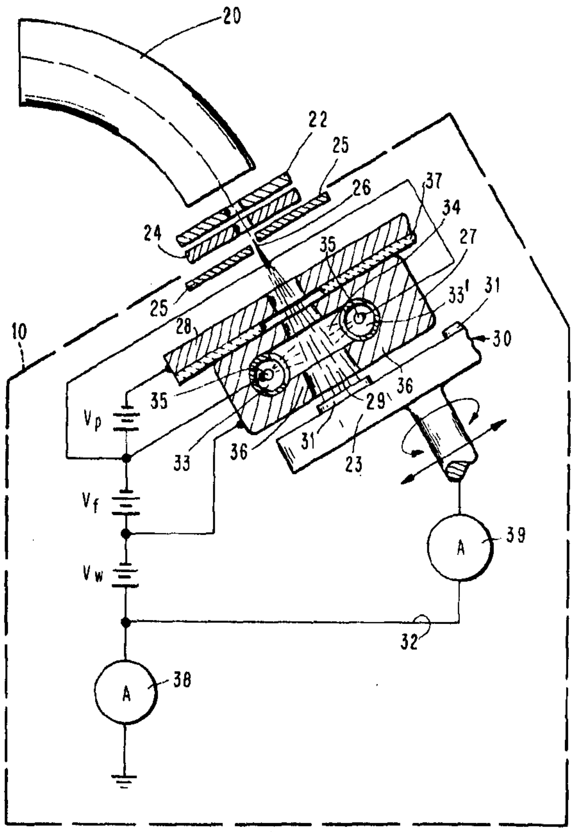
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FIG. 1A

1584224 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

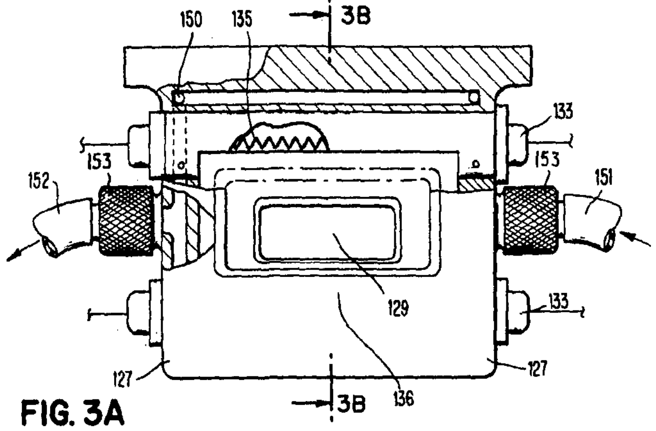

FIG. 3A

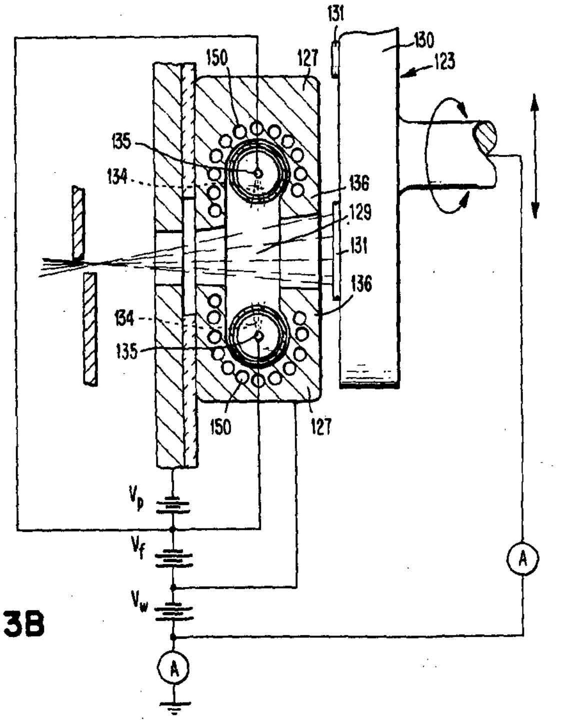

FIG. 3B