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Boroffka et al.

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[54] **ION IMPLANTATION PROCESS**

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[52] **U.S. Cl.** **148/1.5;** 148/190; 357/91

[51] **Int. Cl.**[2] **H01L 21/265**

[58] **Field of Search** 148/1.5, 187, 189, 190; 204/164; 317/235

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[57] **ABSTRACT**

A technique for simplifying ion implantation so that a plurality of different ions may be implanted in a single object without long periods of time between implantations. The technique utilizes, in a given ion source, a select initial substance to be ionized which initial substance contains all of the ions to be implanted. Then during the subsequent implantation procedure the ions are either simultaneously or sequentially implanted into the object.

13 Claims, 7 Drawing Figures

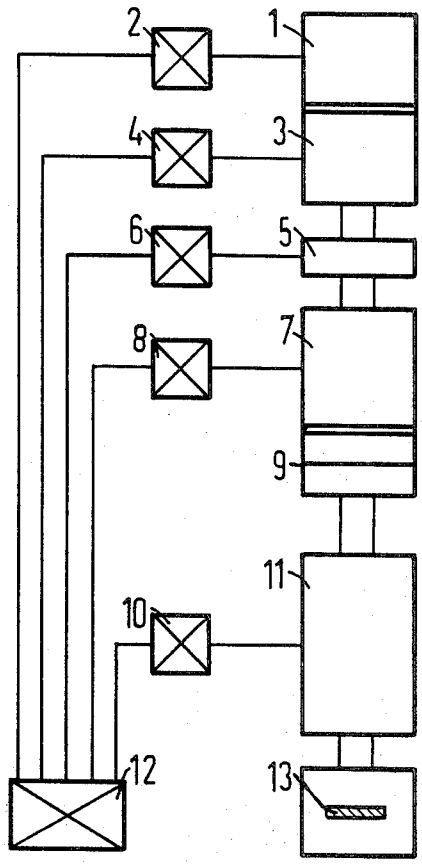


Fig. 1

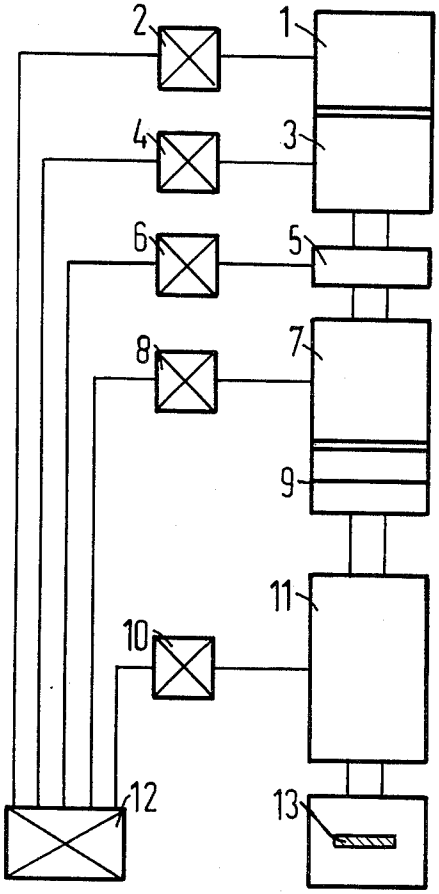
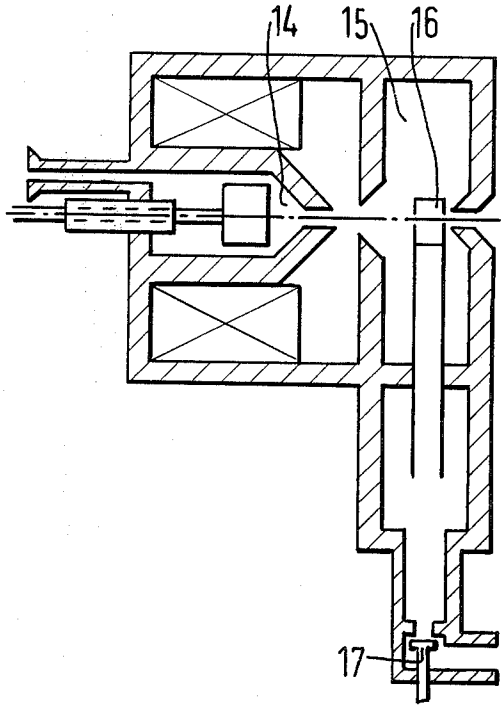


Fig. 2



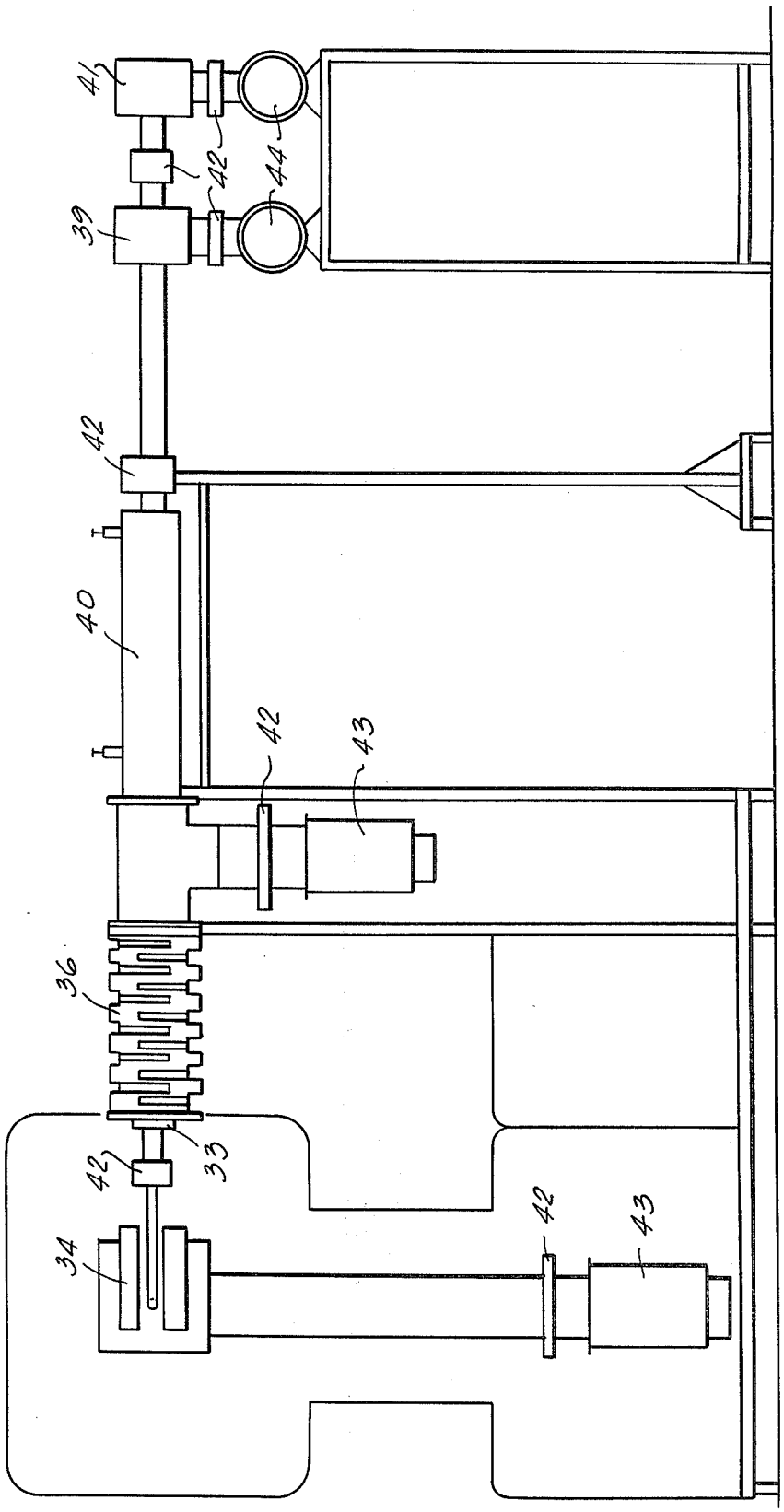


Fig. 3

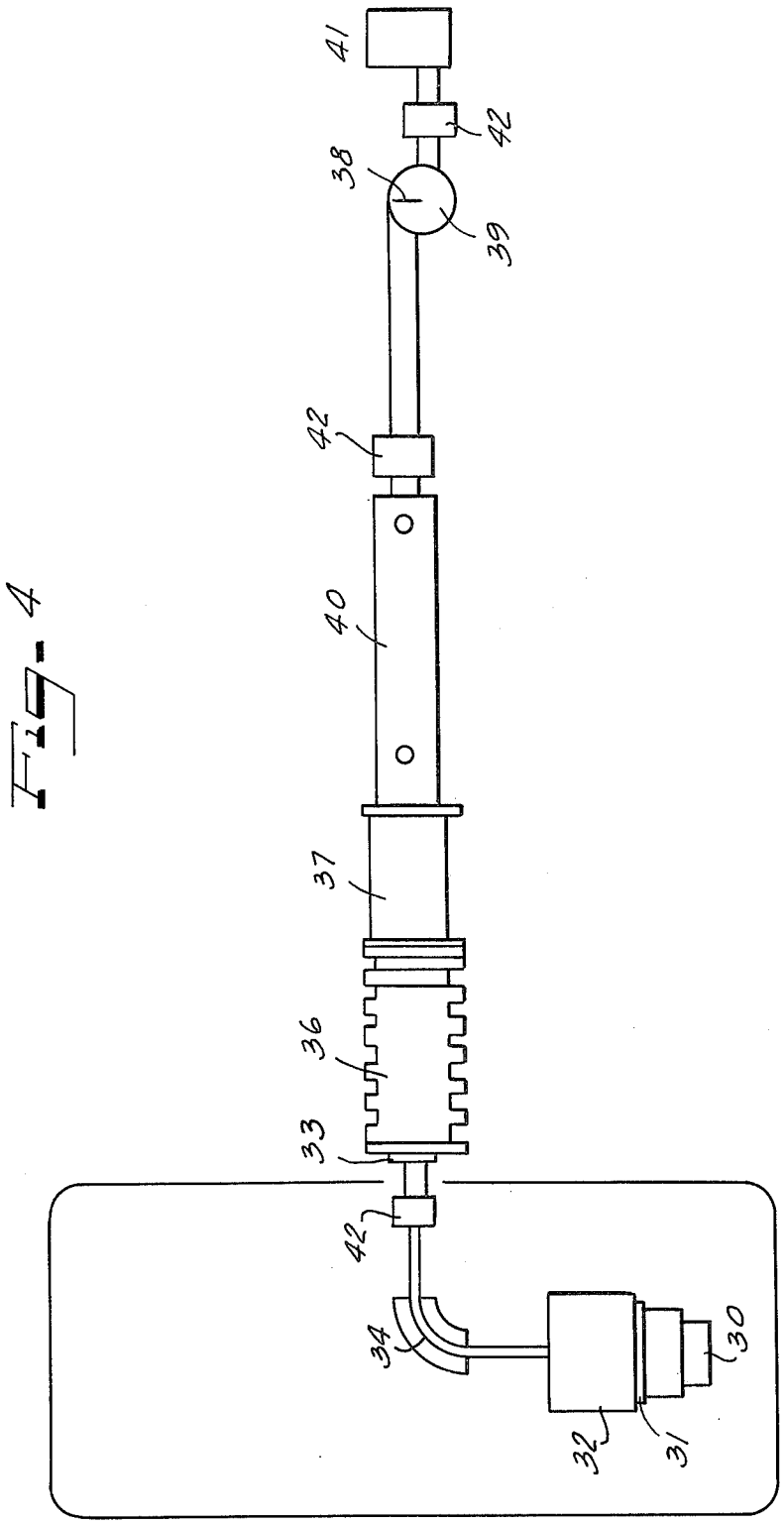


Fig. 4

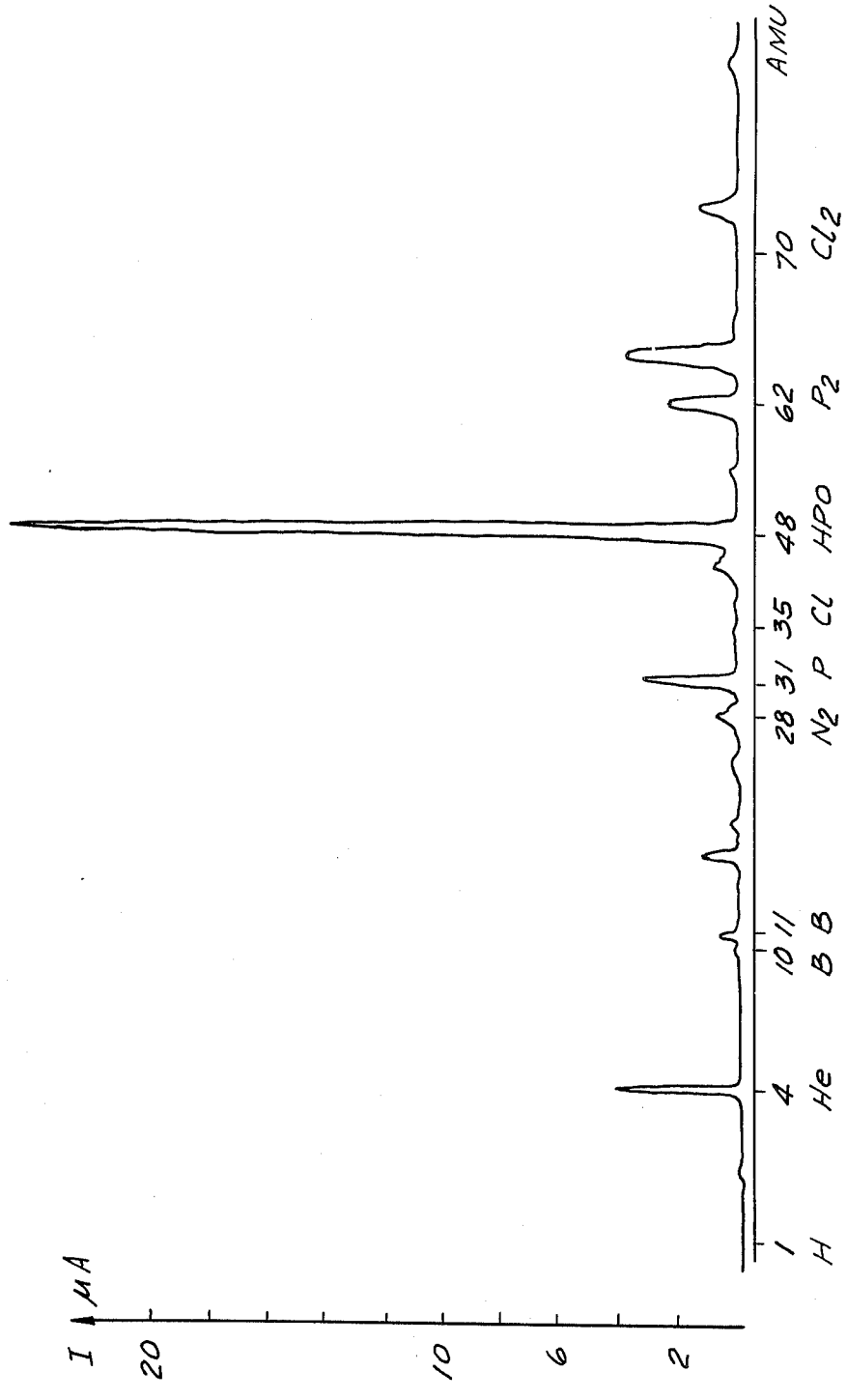


Fig. 5

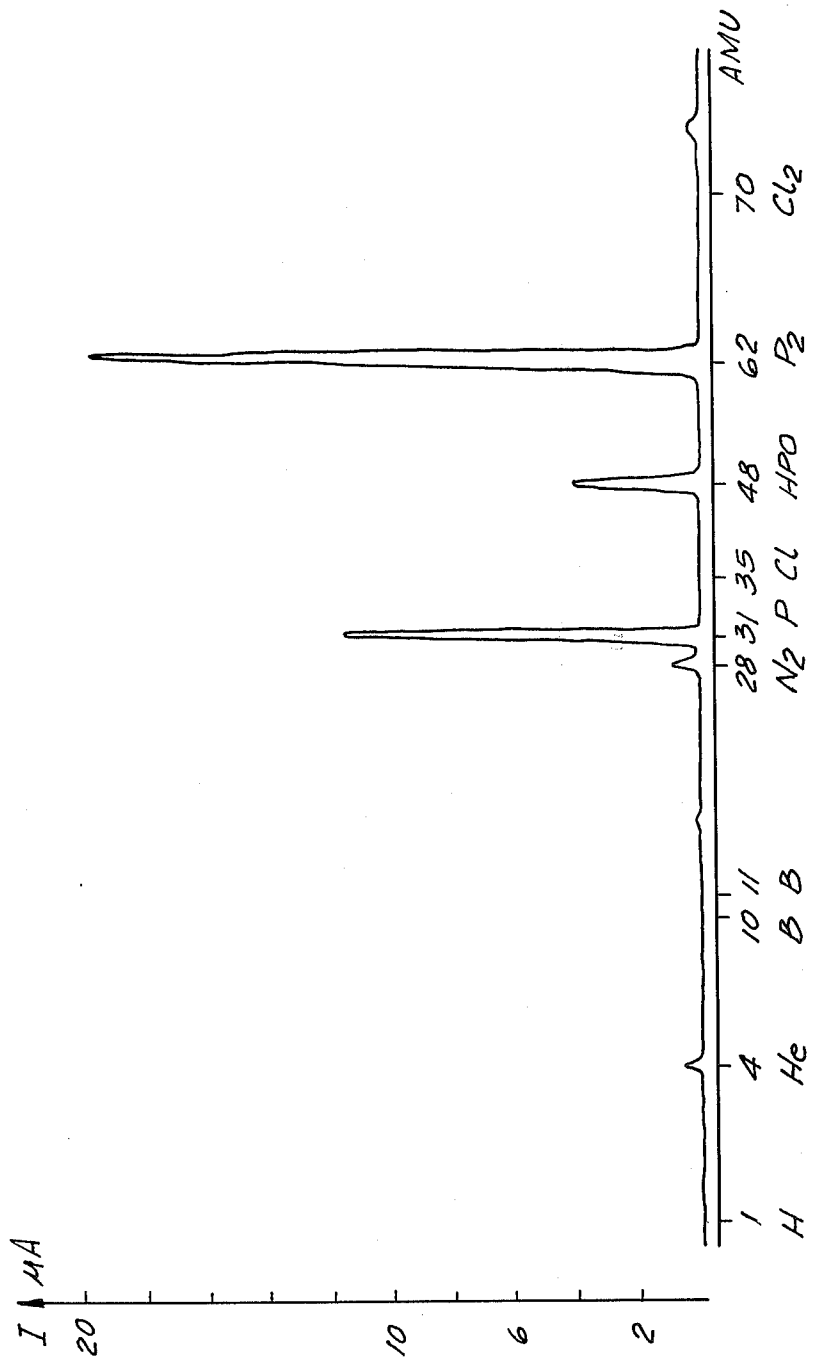


Fig. 6

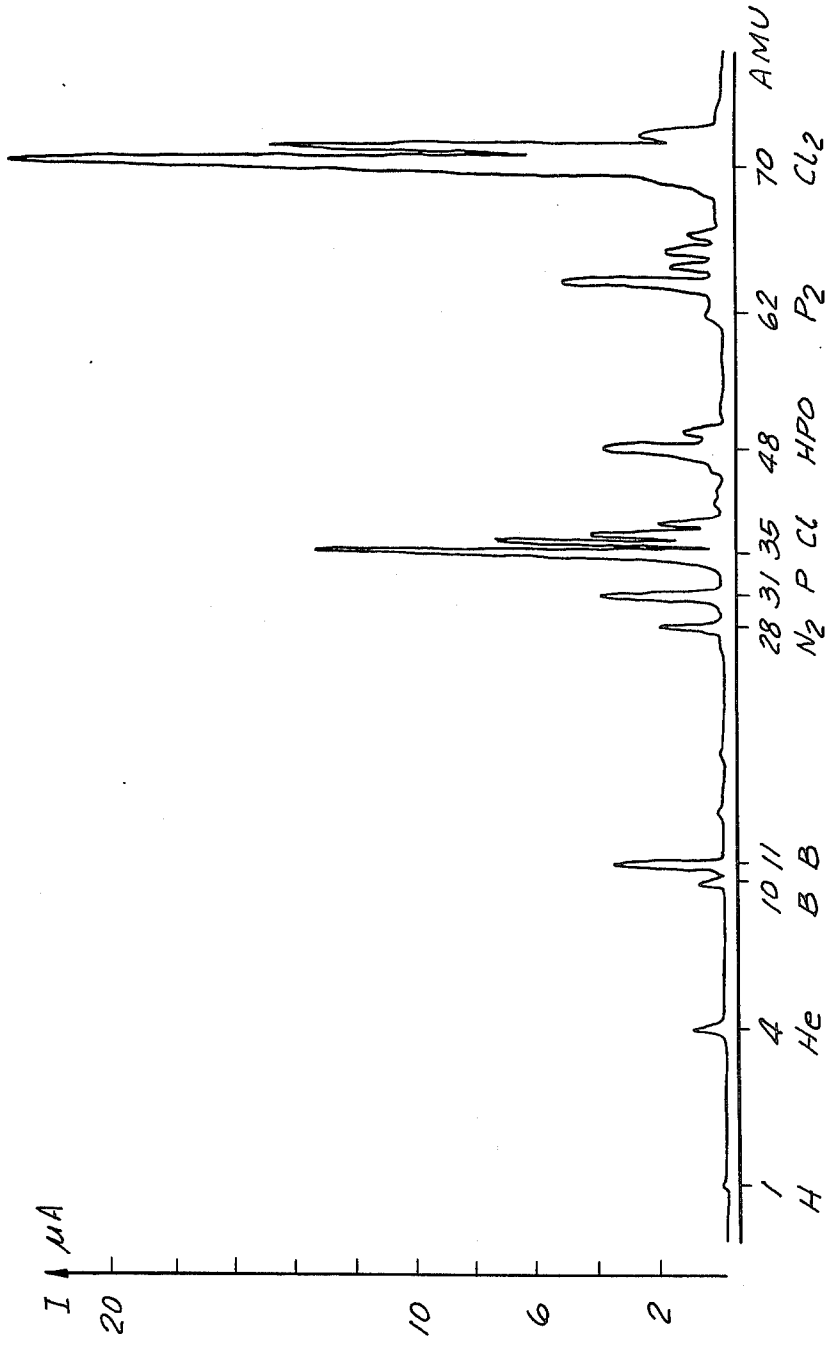


Fig. 7

ION IMPLANTATION PROCESS

BACKGROUND OF THE INVENTION

In the previously known ion implantation units, ions of one type are implanted in an object using an ion source which contains a substance which will produce such one ion type. For implantation of other types of ions into the same object, it is necessary by the known processes to use sequential implantation procedures wherein the ion source, or the substance used for generating a desired ion type, is changed between such successive implantations.

Each such change-over requires a relatively long period of time, usually well in excess of one quarter hour, and commonly as long as two hours, or even longer, which is objectionally long from the viewpoints of production and efficiency of equipment utilization.

BRIEF SUMMARY OF THE INVENTION

The process of this invention advantageously results in a considerable simiplification of prior art ion implantation techniques, especially of multiple implantation techniques of the type used in the production of complicated implantation profiles, such as are used in making hyperabrupt diodes. Multiple implantation as used herein has reference to the implanting of different types of ions into the same object or target with identical or varying energies and dosages.

The process in accordance with the invention may be advantageously applied also when individual implantations with different types of ions are to be effected in consecutively implanted objects.

An aim of the invention is to provide a process for ion implantation with the aid of which an object being implanted with ions can, without a time consuming change of ion source, be subjected in relatively rapid succession to ions of various types, and/or can be simultaneously subjected to ions of two or more types.

An advantage of the process of the invention is that the long periods of time heretofore required by the prior art for changing from one ion type or source to another may be reduced to changeover times which may be as brief as a few seconds.

Another advantage of the process of this invention results where an ion implantation is effected in objects which are maintained at high temperatures because, by the present process, in contrast to the processes of the prior art, objects at high temperatures can be implanted with different types of ions in rapid succession before the profile of a type of ion already implanted in the object changes.

Other and further objects, aims, advantages and purposes will be apparent to those skilled in the art from a reading of the present specification, drawings and claims.

BRIEF DESCRIPTION OF DRAWINGS

In the drawings:

FIG. 1 is a schematic, diagrammatic view of the class of ion implantation apparatus useful in the practice of the process of the present invention;

FIG. 2 is a vertical, sectional, schematic, detailed view of one type of ion source useful in the apparatus of FIG. 1;

FIG. 3 is a simplified, partially diagrammatic view in side elevation of one embodiment of apparatus used to practice the process of the present invention;

FIG. 4 is a view similar to FIG. 3, but showing a top plan view of such apparatus;

FIG. 5 shows a mass spectrum plot of an ion emission stream produced in accordance with the teachings of this invention derived from the compound B P as the initial substance;

FIG. 6 shows a mass spectrum plot of an ion emission stream produced in accordance with the teachings of this invention derived from a mixture of amorphous B (boron) and amorphous P (phosphorous) as the initial substance; and

FIG. 7 shows a mass spectrum plot of an ion emission stream produced in accordance with the teachings of this invention derived from a mixture of BCl_3 and PCl_3 as the initial substance.

DETAILED DESCRIPTION

By the present invention, an ion source is supplied with an initial substance which (may be in the form of an alloy) containing all the elements to be ionized which are necessary for an ion implantation, and such initial substance is chosen so that the various, required types of ions desired for an implantation are produced either simultaneously or sequentially. Through the control of a mass separator, the particular type or types of ions so chosen can be deflected towards the object being implanted in each case at a given prechosen or selected instant of time.

The selection of such initial substance preferably takes place in dependence upon the type of ion source used in any given instance, in which connection, for example, the vapor pressure, the ionization energy, the dissociation energy, and/or the nature of the bond of the initial substance must be taken into account. These initial substances preferably comprise a plurality of chemical compounds which may or may not form addition compounds or the like.

The process of this invention utilizes an ion implantation unit comprising of an ion source, an extraction element, a mass separator, a focusing device, and an object holder, as those skilled in the art will appreciate.

Referring to FIG. 1, there is seen an ion source 1 of an ion implantation unit which source 1 is supplied with the initial substance. In accordance with this invention, this initial substance comprises a mixture of chemical compounds which contain the various types of ions necessary for a desired implantation of an object secured in the object holder 13. Preferably, the initial substance comprises alloys, or mixtures of different compounds which are ionizable to the ions desired in a given situation. Those skilled in the art will appreciate that the ion source 1 is adapted to the state of matter of the initial substance.

The art knows of various ion sources; these include, for example, the duoplasmatron type with or without furnace, arc sources, high frequency sources, Penning sources, sputtering sources, and the like.

In FIG. 2 is schematically shown an ion source of the duoplasmatron type, for present illustrative purposes. This ion source utilizes a stage 14 wherein electrons and Helium-ions are produced in a helium plasma. These electrons ionize vapors in the expansion chamber 15. Vapors in expansion chamber 15 are produced by the vaporization of solid bodies of an initial substance in the furnace 16. If the initial substance is in a gaseous form at room temperature, such gaseous initial

substance is admitted into the expansion chamber **15** via valve **17.**

In the ion source **1,** all of the substances comprising the initial substance are ionized and are accelerated by the electric field of an extraction element **3** downstream from, but adjacent to, the ion source **1.** Subsequently, the ions produced in the ion source **1** pass through a focussing device **5** and then into a mass separator **7.** Mass separator **7** may be, and preferably is, for examples, a deflecting magnet, a Wien filter, or the like. In another ion implantation unit suitable for the practice of the present invention, the mass separator may be, for example, a so-called resonance analyser, such as a quadrupole analyser.

The resolving power of the mass separator **7** is selected to be such that substantially only ions of one type pass through the outlet gap **9** of the mass separator **7.** Ions of one type which leave the gap **9** of the mass separator **7** hit an object secured in the object holder **13** so that ion implantation of such object is accomplished.

In a further embodiment of an ion implantation unit adapted for use in the process of the present invention, ions of one type which leave the outlet gap **9** are post accelerated by the field of a post accelerator which follows the mass separator **7.** In FIG. **1,** for example, a post acceleration unit is referenced by the numeral **11.**

Those skilled in the art will appreciate that the ion optical elements used in an ion implantation unit adapted for use in practicing the process of the present invention may be arranged in any convenient sequence, as desired.

Simultaneous implantations of two different types of ions can be achieved in accord with this invention if the mass separator **7** takes the form, for example, of a resonance analyser, and this resonance analyser is operated at higher modes.

In FIG. **1,** the power supply of the ion source **1** is marked **2;** the power supply of the extraction element **3** is marked **4;** the power supply for the focussing device **5** is marked **6;** the power supply for the mass separator **7** is marked **8;** and the power supply for the post acceleration unit **11** is marked **10.** A process control unit **12** is preferably connected to all the current and voltage supplies.

Selection of a desired ion type from the sum of the ions of various types produced in the ion source **1** takes place by means of mass separation in the mass separator **7.** The change-over from one ion type to another is achieved by changing the fields used in the mass separator **7.** For examples, the field of a quadrupole analyser, or of a Wien filter, may be changed in fractions of a second either manually, or in semi-automatic process controlled fashion, as desired.

The process of the present invention may be employed for the implantation of a complicated doping profile such as, for example, may occur in the manufacture of a hyper-abrupt diode, or a pn- junction in a varactor diode. In such cases, the doping preferably takes place in process-controlled fashion.

The present invention, in one aspect, involves a process for ion implantation of a target object using an ion implantation unit which comprises an ion source, an extraction element, a mass separator, a focussing device, and an object holder, as indicated. This process comprises a series of steps.

In a first step, one charges said ion source with a composition comprising at least one vaporizable compound containing all elements types to be ionized and implanted.

Then, one vaporizes said composition in said ion source thereby generating an ion beam therefrom which contains all ion types to be implanted. This beam is passed into the said mass separator.

One regulates the electrical energy applied to said mass separator at a value which is adapted to permit passage therethrough of substantially only ions of one type within such beam.

Then, one impacts such one type of so-passed ions as a beam against a predetermined said target object at a predetermined energy and in a predetermined profile.

Thereafter, one changes the electrical energy applied to said mass separator to a value which is adapted to permit passage therethrough of substantially only ions of another type within such group, and then one impacts such other type of so passed ions as a beam against said predetermined target object at a predetermined energy and in a predetermined profile. These last steps are repeated until all of the ion types to be wanted in said beam are successively so respectively impacted against said target object.

The present invention is illustrated with boron and phosphorous because at present, these are the most widely used dopants in silicon, but those skilled in the art will appreciate that the present invention may be used widely. However, the present invention may be practiced with the compound BP and is at present most preferably practiced with BCl_3 and PCl_3. Most preferably, these compounds are used at the rate of one part BCl_3 to ten parts PCl_3.

Several additional advantages of using $BCl_3 . PCl_3$ as a starting substance for B^+ or P^+ ion production should be mentioned:

1. The vapor pressure of $BCl_3 . PCl_3$ at room temperature is less than **1** bar, so that the substance does not need to be stored in melted off glass containers.

2. The addition compound $BCl_3 . PC1_{PCl}$ is much less aggressive than, for example, BCl_3 alone.

3. The vacuum system of the ion implantation unit does not need recovery time after having stopped the $BCl_3 . PCl_3$ input to the ion source in contrast to the application of a simple compound such as BCl_3 where vacuum system recovery times of from about 2 to 3 hours are normal.

4. The B^+ and P^+ ion currents are stable after setting the suitable pressure in the ion source without any further change of the adjustment parameters of the ion source. In contrast to that achieved by application of solid elements B and P, the heating power of the oven of an ion source has to be controlled permanently.

The following Embodiments demonstrate that the ion implantation process of this invention speeds up the feeding of the ion source with the proper starting substances. In these examples, the results were obtained using a duoplasmatron ion source, but those skilled in the art will appreciate that other ion sources will give other specific results yet will not change the main feature of the invention described herein.

EMBODIMENT

The present invention is further illustrated by reference to the following Examples. Those skilled in the art will appreciate that other and further Examples are ob-

vious and within the spirit and scope of this invention without departing from the teachings of the present Examples taken with the accompanying specification and drawings. All parts are parts by weight unless otherwise indicated.

Example A

The ion implantation system used here is shown in FIGS. 3 and 4 and is comprised of an ion source 30 of the duoplasmatron type which is equipped with a 15 k V extraction element 31. An electrostatic lens 32 focuses the ion beam (not shown) on the exit aperture 33 of the magnetic mass-separator 34. The accelerator 36 provides means for imparting additional acceleration to ions between acceleration potentials ranging from 0 to 300 k V. The electrostatic quadrupole lens system 37 focuses the ion beam onto an object or specimen 38 located in the target chamber 39. The x, y-scanning system 40 sweeps the ion beam over object 38 to produce uniform irradiation over the whole object 38. The chamber 41 serves as an airlock for target chamber 39. A set of specimens can be preevacuated in the airlock chamber 41 before being moved individually or in groups into target chamber 39. The valves 42 separate different sections of the system from one another. The diffusion pumps 43 and the turbomolecular pumps 44 evacuate the system. An ultra high vacuum technique is used which provides that residual gas pressure, neutral beam contamination of objects (or specimens) being implanted, and X-ray emission are maintained at low levels. In the following Examples, all ions are accelerated to an energy of 15 ke V.

EXAMPLE 1

Using the foregoing apparatus, BP as the initial substance is heated to above about 800°C. in the oven of the ion source 30 to obtain a vapor pressure of about 5×10^{-1} Pa in the ion source. At equilibrium, a low but constant B_{11}^+ ion current of about 0.75 μA and a higher P_{31}^+ ion current of about 4μA (microamperes) is observed. As shown in FIG. 5, the mass spectrum shows peaks of B_{11}^+ and P_{31}^+ with a strong contribution of impurities as a result to the high oven temperature. During the initial use of the oven temperature, a very strong P^+ peak is observed which is reduced after equilibrium conditions are obtained. The target object is found to be implanted with both P_{31}^+ and B_{11}^+ ions subsequently.

EXAMPLE 2

Using the foregoing apparatus, of Example A, a mixture of B and P as the initial substance is heated to above about 200° C. in the oven of the ion source 30, it is found that a homogeneous mixture of amorphous B and amorphous P does not deliver B^+ as long as the temperature in the oven does not exceed temperatures which limit seriously the life time of the duoplasmatron ion source used here. As shown in FIG. 6, the mass spectrum shows exclusively P^+, P_2^+, and P_4^+ ions under this condition. Hence, such initial substance is generally equivalent to the prior art and is not suitable for the practice of the present invention.

EXAMPLE 3

Using the foregoing apparatus of Example A, a mixture of BCl_3 and PCl_3 as the initial substance is used (but without heating) in the ion source 30 with a vapor pressure of about 5×10^{-1} Pa in the ion source. After pilot tests with BCl_3 and with PCl_3, the ion source is fed with a mixture of one part PCl_3 and ten parts PCl_3 resulting in an addition compound, $BCl_3 \cdot PCl_3$. As FIG. 7 shows, the mass spectrum shows B_{11}^+ and P_{31}^+ ion currents of almost the same strength of approximately 4μA. The ion currents are stable and mainly easier and better reproducible to adjust than supplying the ion source only with the component compounds which is utilized for the implantation to be done in this time (see Example 2). The target object is found to be implanted with both P_{31}^+ and B_{11}^+ ions subsequently. Using this procedure, multiple implantations with B^+ and P^+ are thus performed in by changing only the exciting current of the magnet of the mass separator 34, a procedure which need not consume more time than approximately 30 seconds. Hence, the excessive exchange times of dopants of the prior art are overcome.

EXAMPLE 4

Another example successfully proved is the application of GaAs to produce Ga and As ions respectively.

We claim:

1. In a process for ion implantation with an ion implantation unit in which said unit comprises an ion source, an extraction element, a mass separator, a focussing device and an object holder, the improvement which comprises the steps of charging to said ion source a composition comprising chemical compounds which contains all the elements to be ionized which are required for the desired implantation, said composition being adapted to produce all required ion types in said ion source either simultaneously or sequentially, and directing said ions so produced from such ion source as a beam along one beam path towards a target object, the ions in said beam being controlled by said mass separator so that a particular type or types of ions desired are deflected onto said target object at a given prechose, desired instant of time at a predetermined energy and in a predetermined profile.

2. The process of claim 1 wherein said composition consists of a mixture of at least two compounds.

3. The process of claim 1, wherein said composition consists of an alloy.

4. The process of claim 1 to 3, wherein the selection of a single ion type with which said target object is to be irradiated from among the total number of ion types produced by said ion source is accomplished through a change in electromagnetic fields exerted by mass separator on ions passing therethrough.

5. The process of claim 4 wherein said change in said mass separator takes place by means of automatic process control.

6. The process of claim 1 to 5, wherein said implantation occurs in a predetermined dose or profile by means of automatic process control.

7. The process of claim 4 to 6, wherein multiple doping of a target object with various ions is accomplished in predetermined, respective profiles.

8. A process for ion implantation of a target object using an ion implantation unit which comprises an ion source, an extraction element, a mass separator, a focussing device, and an object holder, said process comprising the steps of

A. charging said ion source with a composition comprising at least one vaporizable compound containing all elements types to be ionized and implanted,

B. vaporizing said composition in said ion source generating an ion beam therefrom which contains all ion types to be implanted, and passing said ion beam into said mass separator,

C. regulating the electrical energy applied to said mass separator at a value which is adapted to permit passage therethrough of substantially only ions of one type within such beam,

D. impacting such one type of so-passed ions as a beam against a predetermined said target object at a predetermined energy and in a predetermined profile,

E. thereafter changing the electrical energy applied to said mass separator to a value which is adapted to permit passage therethrough of substantially only ions of another type within such group,

F. impacting such other type of so-passed ions as a beam against said predetermined target object at a predetermined energy and in a predetermined profile, and

G. repeating steps (E) and (F) until all ion types to be implanted in said beam are successively so respectively impacted against said target object.

9. The process of claim **8** wherein said composition comprises B P.

10. The process of claim **8** wherein said composition comprises a mixture of BCl_3 and PCl_3.

11. The process of claim **10,** wherein said composition contains one part BCl_3 and ten parts PCl_3.

12. The process of claim **8,** wherein all ions are accelerated to an energy of 15 ke V.

13. The process of claim **8** wherein said composition comprises the compound GaAs.

* * * * *