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EUROPEAN PATENT APPLICATION

21 Application number: **78300268.6**

61 Int. Cl.²: **H 01 J 27/00, H 01 J 3/04**

22 Date of filing: **08.08.78**

20 Priority: **08.08.77 US 822966**

43 Date of publication of application:
21.02.79 Bulletin 79/4

64 Designated contracting states:
BE DE FR GB NL SE

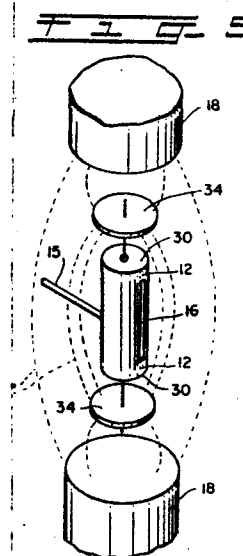
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64 Plasma discharge ion source.

57 It has been found that the proportions of the various ions produced by a plasma discharge source depends on the temperature of the plasma. In this invention means are provided increasing the temperature of the plasma. This is achieved by an arrangement (18, 34) which provides a containing field 32 which restrains the passage of electrons from the plasma to the anode (12), both radially outwards and axially to the end walls (30).



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Plasma Discharge Ion Source

This invention relates to ion sources, and particularly to the type of ion source in which a compound of the material of a desired ion is dissociated in a plasma discharge process to provide a beam of charged particles. The beam includes the desired ions, which are generally subsequently separated from the beam by mass-charge separation techniques.

Plasma ion sources are well known, see, for example, FIG. 2 of U.S. Patent 2,373,151, issued April 10, 1945. One problem with prior art plasma dissociation ion sources is that it has not been known how to control fully the dissociation process, whereby the proportion of the desired ion in the output current is generally significantly less than what, at least, would appear to be possible. For example, if singly charged boron ions are desired from a source gas of a compound of boron, the total quantity of boron in the desired ionic form has, heretofore been significantly less than the total quantity of boron present in the gas. That is, because it has not been known how to control fully the extent and completeness of the dissociation process, most of the boron present in the gas remains tied-up in non-useful molecular and electrically neutral forms.

Thus, for the purpose of increasing the usefulness and efficiency of such ion sources, a need exists for controlling the dissociation process for selecting and optimising the proportions of selected ions

in the ion source output current.

The present inventor has discovered that the proportions of the various ions in the ionic output current depends on the ion source plasma temperature and that the lack of control over the dissociation process in known ion sources is due to the limited maximum plasma temperature which could be obtained. Accordingly the present invention provides means for increasing the plasma temperature. It has also been found that a significant mechanism whereby the plasma loses energy and which therefore limits the maximum temperature is axial drift of electrons to the anode of the ion source. Thus the plasma temperature can be increased by restraining the axial drift of electrons to the anode.

Some embodiments of the invention will now be described by way of example with reference to the accompanying drawings of which:-

FIG. 1 is a schematic illustration of a prior art ion source;

FIGS. 2 and 3 are graphs showing the proportion of the various ions in the output current from an ion source of the type shown in FIG. 1 plotted against plasma temperature; FIG. 2 being for a source gas of boron trifluoride, and FIG. 3 being for a source gas of boron trichloride;

FIG. 4 is a cross-sectional view of the anode of the ion source shown in FIG. 1 and illustrating a magnetic field configuration used in accordance with one embodiment of the invention;

FIG. 5 is a view similar to that of FIG. 1 but showing a modification of the prior art ion source for providing the magnetic field configuration illustrated in FIG. 4; and

FIG. 6 is a view similar to that of FIG. 4 but showing a modification of the interior of the anode in accordance with a different embodiment of this invention.

Ion sources which rely upon the plasma dissociation of a gaseous source material are well known.

With reference to FIG. 1, an example of a known source 10 is shown as comprising a generally closed cylindrical anode 12 of, for example, graphite or tantalum, having disposed therein (see also FIG. 4) an axially extending electrical resistance heated filamentary cathode 14. The source 10 is contained in an evacuated chamber (not shown), and a gaseous compound of the desired ionic material is passed through the anode between an input tubing 15 and an exit slit-like opening 16. A steady voltage differential is established between the anode and the cathode, the voltage being of sufficient amplitude to cause an electric discharge through the gas between the cathode and the anode. The electric discharge causes a dissociation of the gas into various neutral and charged particles. The neutral particles exit as part of the gas flow through the slit 16, and the charged particles, both positive and negative, fill the space within the anode 12. Positively charged particles which drift close to the slit 16 are extracted from the anode 12 and are accelerated by an electric field external to the source 10 to provide the beam of charged particles. The desired particles are separated from this beam using known mass-charge separation techniques.

For increasing the number of charged particles, that is, the density of the plasma within the anode 12, a magnet 18 is used to provide an axial magnetic field (represented by the dashed lines 19) about and within the anode 12. Such axial field tends to increase the path length of the plasma electrons, and thus the plasma density, by inducing the electrons to circle about the cathode rather than proceeding relatively directly from the cathode towards the anode. Also, because of the flow of current along the cathode 14, an additional magnetic field is present which causes the electrons to drift axially along the length of the anode towards the anode axial ends 30 where the electrons are collected. The importance of this electron axial drift is discussed hereinafter.

As previously noted, a shortcoming of such ion sources as used in the past is that the proportion of the

desired ions in the ion beam is not significantly controllable, with the general result that only a relatively small quantity of the desired ions is available.

For example, a common source material for
5 the production of singly charged boron ions (B^+) is boron trifluoride (BF_3), a gaseous material at room temperature. (Elemental boron is not used as a source material owing to its high vaporization temperature.) Mass spectrographic analysis of the ionic beam produced using this source
10 material reveals the presence of the desired boron ions, but also such ions as BF^+ and BF_2^+ , with the proportion of the desired singly charged boron ions to the total beam current (depending upon the particular ion source used) being generally less than 15 percent. That is, although the
15 ion current contains much boron, much of it is tied up with fluorine atoms in non-useful forms.

The present inventor has discovered that the proportion of the various ions in the ion beam is a function of the temperature of the ion source plasma, and
20 that the proportion of a selected ion of the beam current can be optimised to an extent not heretofore possible by control and selection of the plasma temperature. This is explained as follows.

In the plasma dissociation process, various
25 collisions occur among the gas molecules and fragments thereof, and between the plasma electrons and the gas particles. While both types of collisions cause fragmentation of the gas molecules, it is believed that only electron collisions cause ionisation of the particles.

30 The output beam from the ion source contains all the different positive ions produced in the dissociation process. The present inventor has demonstrated, however, that the proportion of these different ions in the beam depends upon the statistical probability or rate of
35 occurrence of the different types of possible collisions, that is, upon the probability that certain fragments will be produced in the dissociation process, and upon the probability
38 that these fragments will collide with electrons of

sufficient energy to cause ionisation thereof. Such probabilities, in turn, are a function of the dissociation and ionisation energies of the impacted particles and a function of the energy of the impacting electrons. Thus,
5 for a given source material, the probability of the occurrence of various collisions, and thus the degree of dissociation and ionisation of the source gas, is a function of the energy distribution of the plasma electrons, that is, of the plasma temperature (kT , where k =
10 Boltzmann's constant and T = temperature in degrees kelvin).

This is illustrated in FIGS. 2 and 3 which show the proportional composition of the ion beam from an ions source of the type shown in FIG. 1 plotted against the plasma temperature in electron volts. FIG. 2 is for a
15 source material of boron trifluoride, and FIG. 3 is for boron trichloride. The data for these graphs were derived mathematically, and owing to certain assumptions made to simply the calculations, it is expected that certain inaccuracies exist. Experimental data do exist, however,
20 which support the general validity of the relationships shown. Thus, based upon these graphs, a desired proportion of any ion in the ion beam can be obtained, within the possible range of proportions of the ion, by adjusting the temperature of the plasma to the corresponding
25 plasma temperature indicated on the graph. Thus, for example, from the graph of FIG. 3, it is determined that the maximum proportion of singly charged chlorine ions (Cl^+) in an ion beam produced from a source gas of boron trichloride is obtained at a plasma temperature of about 1.0 eV.
30 Similarly, the curves representing the proportions of singly charged boron ions (B^+) begin peaking at a plasma temperature of about 1.5 eV for both source gases (FIGS. 2 and 3).

At relatively low plasma temperatures, such
35 as below about 1.0 eV, the plasma temperature can be adjusted by varying the axial magnetic field strength and/or the anode to cathode discharge voltage. Because the plasma
38 temperature is not strictly an independent variable, being a

function of the plasma density and the particular source gas material used, a trial and error plasma temperature varying process can be used.

It is noted that adjustments of the axial magnetic field strength and discharge voltage amplitude have been made in the past for maximising the quantity of the desired ion in the output current of the prior art ion sources of the type shown in FIG. 1. It has apparently not, however, been heretofore recognised that these adjustments cause variations in the plasma temperature, or that any particular proportion of ions can be selected by proper adjustment of the plasma temperature. Also, the present inventor has determined that the maximum plasma temperature obtainable solely by virtue of adjustments of these parameters is relatively low, whereby the degree of control over the output current proportions has heretofore been quite limited. One technique for increasing the plasma temperature is as follows.

As previously noted, the plasma electrons tend to drift axially along the length of the anode 12. Those electrons which reach the anode axial ends 30 are collected by the anode and are thus removed from the plasma. Because the electrons of highest energy and thus of highest velocity drift the fastest, the higher energy electrons are removed more quickly from the plasma than the lower energy electrons. The result of this is that a disproportionately large number of higher energy electrons is removed from the plasma by collection at the anode axial ends. This tends to reduce the energy distribution of the electrons of the plasma and thus reduce the plasma temperature. Accordingly, one means for increasing the plasma temperature is to reduce the collection of electrons at the anode axial ends.

In accordance with one embodiment of this invention, this is accomplished by modifying the shape of the magnetic field to improve the magnetic "bottle" characteristics of the field. This is illustrated in FIG. 4 which shows a magnetic field (indicated by the dashed



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lines 32) which is more concentrated or constricted at the axial ends 30 of the anode 12 than at the centre thereof. The effect of such a magnetic field shape, as is generally known, is to turn back or "reflect" electrons which are drifting from the central, lower strength regions of the field towards the higher strength axial ends of the field. Thus, as used in the embodiment of the invention shown in FIG. 4, the end constricted magnetic field tends to reduce the drift of electrons towards the axial ends of the anode 12 and to thus reduce the collection of electrons thereat. As aforementioned, such reduction of electron collection causes an increase in the temperature of the plasma.

The greater the ratio of magnetic field strength at the axial ends of the anode to the strength at the centre thereof, the more efficient is the magnetic field "bottle" with respect to increasing the plasma temperature. This ratio is known as the "mirror" ratio.

One means for providing the desired constricted magnetic field of the shape shown in FIG. 4 is by the use of two discs 34 (FIG. 5) of magnetic material, such as steel, disposed closely adjacent to each axial end 30 of the anode 12. The constricting effect of the discs 34 on the magnetic field produced by the magnet 18 is evident by comparison of the arrangement shown in FIG. 5 with the prior art arrangement shown in FIG. 1. The mirror ratio of the magnetic field in the arrangement shown in FIG. 5 is 1.35, whereas the mirror ratio of the prior art arrangement shown in FIG. 1 is 1.17.

The actual increase in plasma temperature caused by the increased mirror ratio is a function of the particular source material used, hence no generalised figures can be given. An example of such increase, however, is as follows.

In use of the prior art ion source 10 shown in FIG. 1, the maximum content of the singly charged boron ion in the output beam heretofore obtainable is about 15 percent with a source gas of boron trifluoride, and about 6 percent with a source gas of boron trichloride. These

boron contents correspond to a plasma temperature of about 1.0 eV with the boron trifluoride source gas (FIG. 2), and about 0.85 eV (FIG. 3) with the boron trichloride source gas. In use of the ion source shown in FIGS. 4 and 5, however, the proportion of singly charged boron ions in the output beam is increased to about 25 percent for the boron trifluoride source gas and to about 10 percent for the boron trichloride source gas. These increases in the proportion of the boron ions in the two output currents correspond to an increase of plasma temperature of about 0.1 eV.

A means for further improving the mirror ratio of magnetic fields for increasing the plasma temperature in ion sources of the type herein described is the substitution of two disc-like permanent magnets (not illustrated) for the steel discs 34 shown in FIG. 5. By proper spacing of such permanent magnets (which would also replace the external magnet 18), a mirror ratio of about 15 is considered possible. An example of such proper spacing is provided hereinafter.

A difficulty with the disc permanent magnet arrangement, however, is that by disposing the permanent magnets close to the anode 12, in order to obtain the necessary magnetic field shaping, the magnets are subject to being heated by radiation from the anode which operates at a quite high temperature. Thus, unless special precautions are taken, such as water cooling of the permanent magnets, overheating of the magnets and destruction of the magnetic properties thereof can occur.

Another means believed effective for increasing the plasma temperature is, as shown in FIG. 6, the mounting of refractory metal shields 36, for example, of tantalum, directly on the filament 14 inside of and closely adjacent to the axial ends 30 of the anode 12.

In use, the shields 36, at filament potential, electrostatically shield the anode axial ends 30 from the plasma and thus reduce the collection of electrons by these portions of the anode. Accordingly, for

the same reasons previously described in connection with the description of the embodiment of the invention shown in FIG. 4, the plasma temperature is increased.

Each of the aforescribed embodiments of the invention is effective to increase the maximum attainable plasma temperature. Such maximum plasma temperatures are obtained at an optimum setting, determined by a trial and error process, of the magnetic field strength and the anode to cathode discharge voltage.

Adjustment of the plasma temperature to less than the maximum possible temperature is possible by adjustments away from the optimum settings of the magnetic field strength and/or the discharge voltage.

With reference again to the embodiment of the invention shown in FIG. 5, it is noted that, with the exception of the inclusion of the magnetic material discs 34, the ion source is identical to the prior art ion source 10 shown in FIG. 1. By way of specific example, in one embodiment of the ion source shown in FIG. 5, the anode 12 has a length of about 7.5 cm. and a diameter of about 2.54 cm. The magnets 18 have a diameter of about four inches (10 cm), and are spaced about 7.5 cm. from the axial ends 30 of the anode 12. The discs 34 have a thickness of about 0.62 cm. a diameter of about 3.75 cm., and are spaced about 1.8 cm. from the anode.

In the aforescribed embodiment in which permanent magnet discs are substituted for the steel discs 34, the permanent magnets can be of identical dimensions and spacings from the anode 12 as aforescribed for the discs 34.

As previously noted, in use of the ion source 10 shown in FIG. 1 according to the prior art, the maximum plasma temperature heretofore obtainable is about 1.0 eV with a source gas of boron trifluoride and about 0.85 eV with a source gas of boron trichloride. An examination of FIGS. 2 and 3, however, reveals that substantial increases in the proportion of singly charged boron ions in the output current are obtainable if higher

plasma temperatures are used. Accordingly, one important use of this invention is the attainment of higher proportions of singly charged boron ions from ion sources of the type described by providing means for increasing
5 the plasma temperature of the ion source beyond that which was previously possible. In particular, increases in the plasma temperature, and corresponding increases of the boron ion content of the output beam are obtained, according to one aspect of this invention, by the use of
10 magnetic fields having a mirror ratio in excess of 1.2. Stated on a different basis, increases in the boron ion proportions are obtained by the use of plasma temperatures in excess of 1.0 eV with a source gas of boron trifluoride and in excess of 0.85 eV with a source gas of boron
15 trichloride. The invention thus finds an application in the production of singly charged boron ions for ion implantation processes such as are employed in the manufacture of semiconductor devices.

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CLAIMS

1. A plasma discharge ion source comprising an anode (12), a cathode (14), means (15) for introducing a gaseous compound between the anode and the cathode, means for establishing between the anode and the cathode an electric discharge of sufficient intensity to dissociate the gaseous compound into a plasma, means (16) for applying a magnetic field to the plasma, and means (17) for discharging ions from the vicinity of the anode and cathode, characterised in that the apparatus includes a pair of members (34), each member being disposed adjacent to a different end (30) of the anode (12) for increasing the temperature of the plasma.
2. An ion source as claimed in claim 1 wherein the members are of a magnetic material.
3. An ion source as claimed in claim 2 wherein the magnetic field applying means comprises a pair of magnetic pole pieces (18) disposed along an axis of the anode, and the members (34) are disposed along the axis between the anode and the pole pieces for constricting the magnetic field at the ends for increasing the mirror ratio of the field.
4. An ion source as claimed in claim 3 wherein the mirror ratio is in excess of 1.2.
5. An ion source as claimed in claim 1 wherein the members are disposed within the anode for electrostatically shielding the ends of the anode from the plasma therewithin.
6. A plasma discharge ion source including an anode (12) forming an elongate chamber, a cathode (14) extending axially through the chamber and plasma containment means (18) to restrain the radially outward passage of electrons from plasma formed within the chamber to the anode characterised in that the plasma containment means is arranged (34, 36) also to restrain axial drift of electrons from the plasma to the anode.
7. An ion source as claimed in claim 6 wherein the plasma containment means (18, 34) is arranged to provide

a magnetic containing field within the chamber having a mirror ratio of at least 1.2.

8. An ion source as claimed in claim 6 wherein the plasma containing means includes
- 5 electrostatic screening means (36) arranged within the chamber to provide the said restraint of axial drift.

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FIG. 1

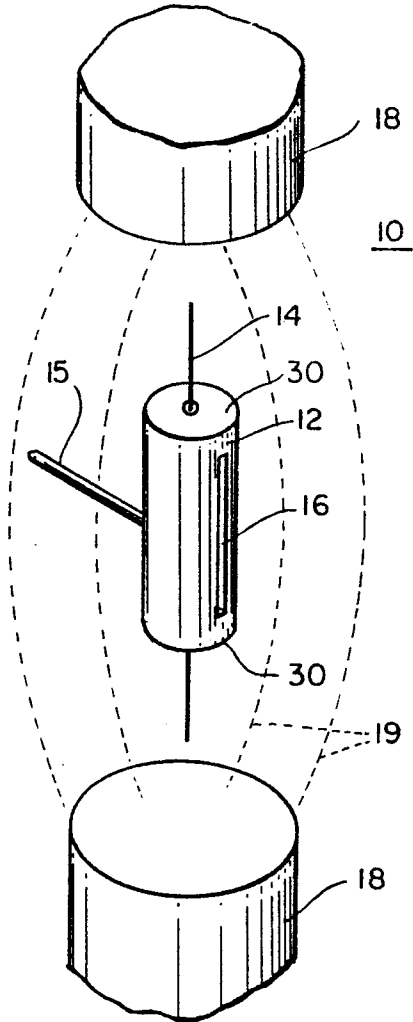


FIG. 5

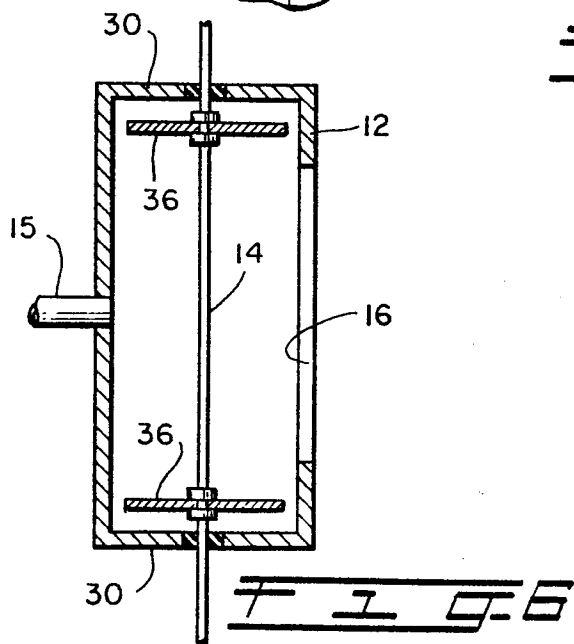
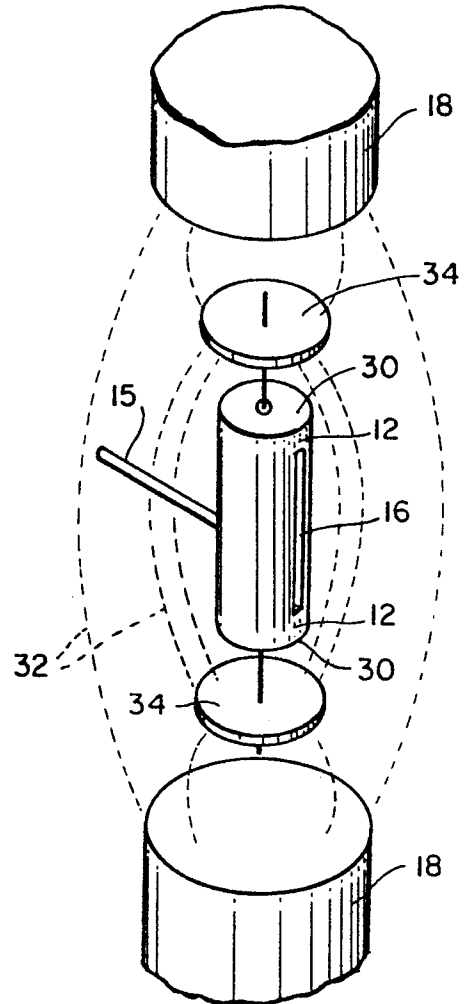
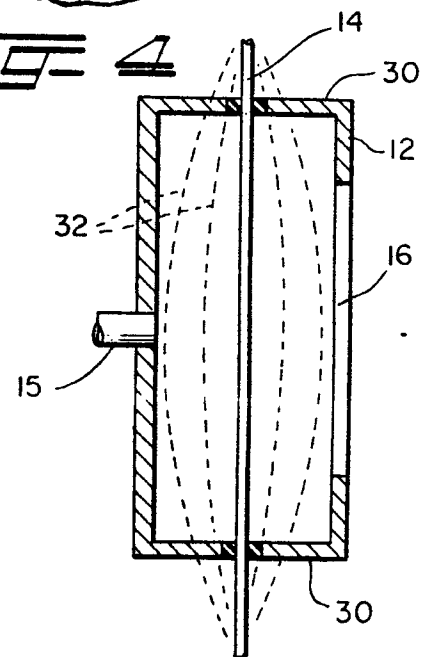
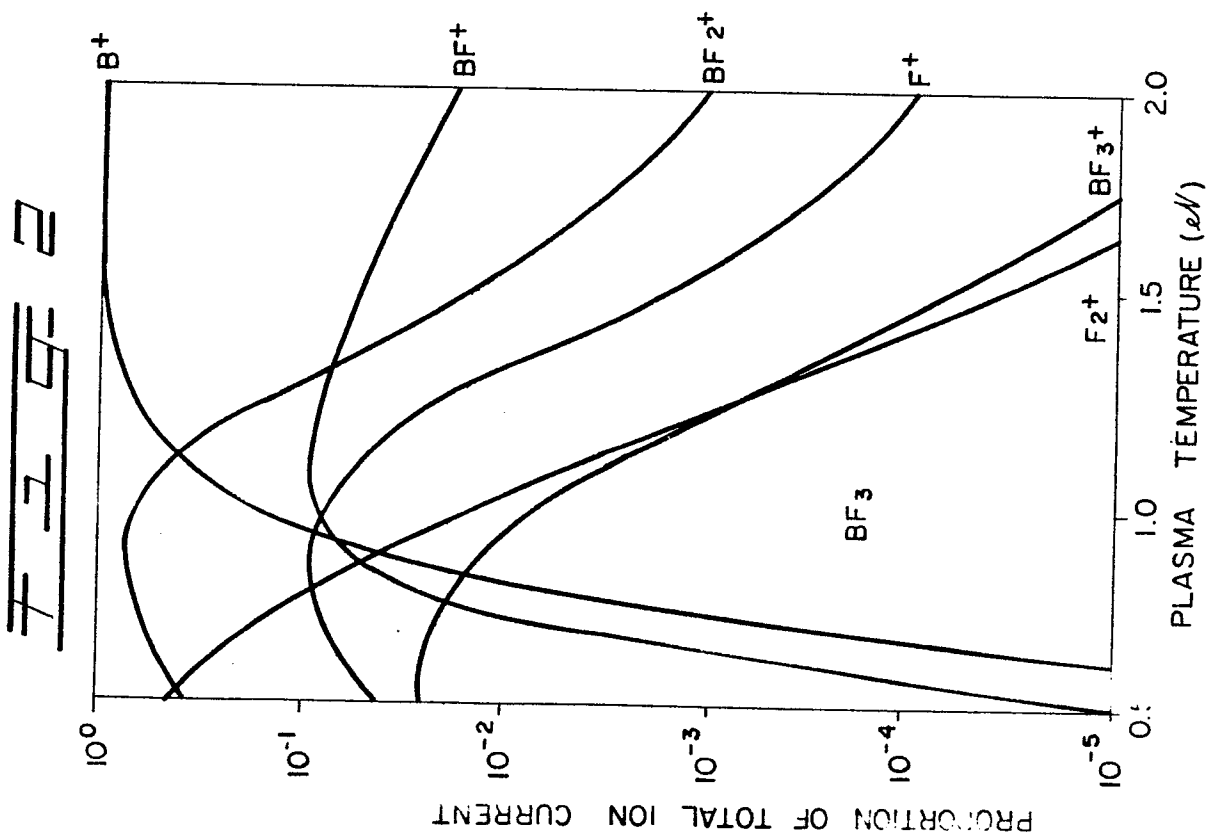
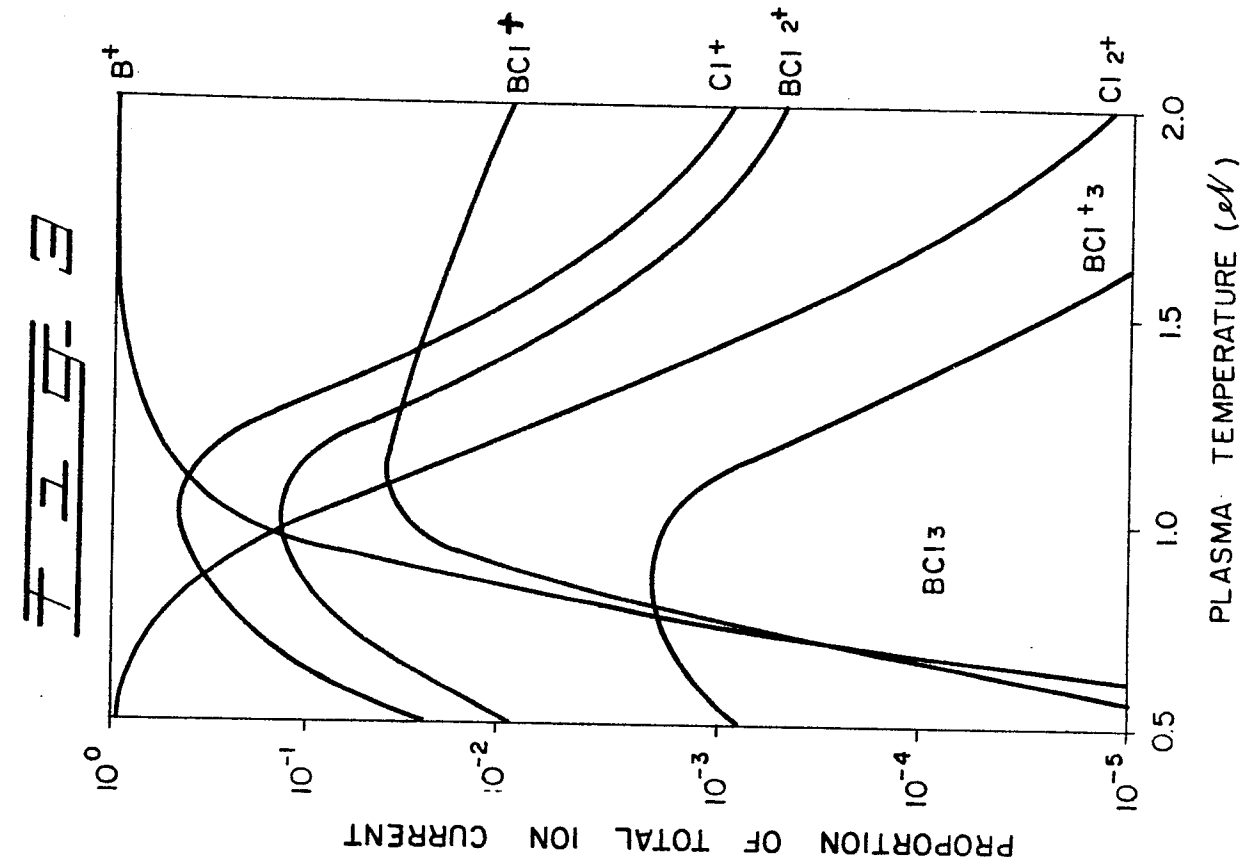


FIG. 4







European Patent
Office

EUROPEAN SEARCH REPORT

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Application number

EP 78 30 0268

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☒ The present search report has been drawn up for all claims			
Place of search	Date of completion of the search	Examiner	
The Hague	16-11-1978	VILLEMIN	



DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	* Page 1, lines 1-2; page 2, line 22 - page 3, line 9; figures * -- IEEE TRANSACTIONS ON NUCLEAR SCIEN-1,3-5, CE, vol. NS-19, no. 2, april 1972, 7 New York International conference on multi- ply-charged heavy ion sources and accelerating systems, held at riverside motor lodge, october 25-28, 1971. Gatlinburg (US) I. ALEXEFF et al.: "Production of Highly Stripped Heavy ions in hot- electron Plasmas produced by an electron beam" pages 195-199. * Page 195, left-hand column line 39 - right-hand column line 10; page 195, right-hand column, line 53 - page 196, left-hand column, line 2; page 199, left-hand column, lines 5-21; figure 1 * -- FR - A - 1 459 469 (I. ALEXEFF et al.) * Page 1, right-hand column, line 22 - page 2, left-hand column, line 30; page 2, left- hand column, line 57 - right- hand column, line 5; page 2, right-hand column, lines 20-28; figures 1,2 * -----	1,3,4, 7	TECHNICAL FIELDS SEARCHED (Int. Cl.)