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[54] **ION SOURCE HAVING A UNIFORM RADIAL DENSITY**

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[51] **Int. Cl.**..**H01j 7/24**

[58] **Field of Search**..........313/63, 230; 250/41.9 SB; 315/111

[56] **References Cited**

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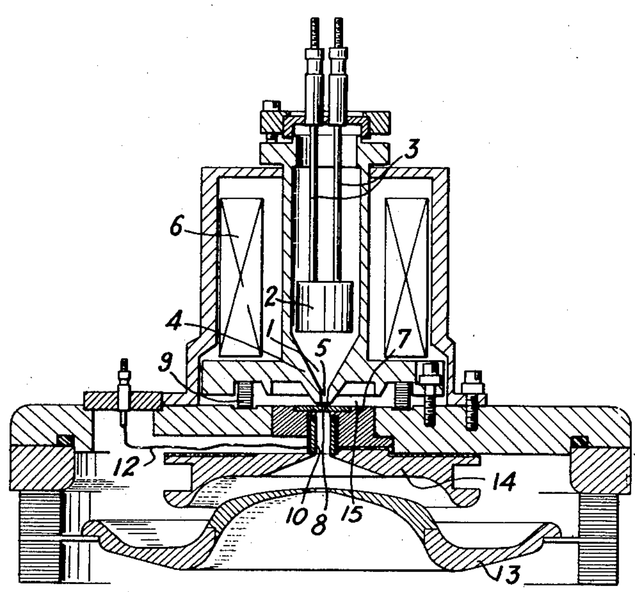
[57] **ABSTRACT**

The source comprises an ionization chamber into which the gas to be ionized is introduced, a cathode placed at the center of an intermediate electrode provided within an orifice for the passage of electrons, an anode provided with a hole for the passage of ions, a plasma-expansion control electrode which is electrically insulated from the anode and brought to a negative potential with respect to the anode potential, and an ion extraction electrode.

4 Claims, 4 Drawing Figures



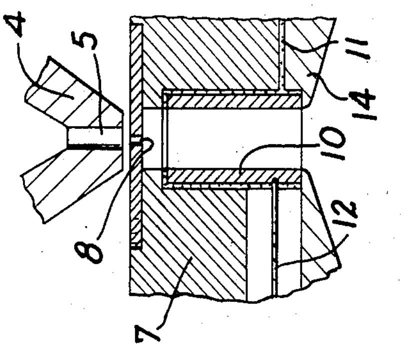


FIG.2

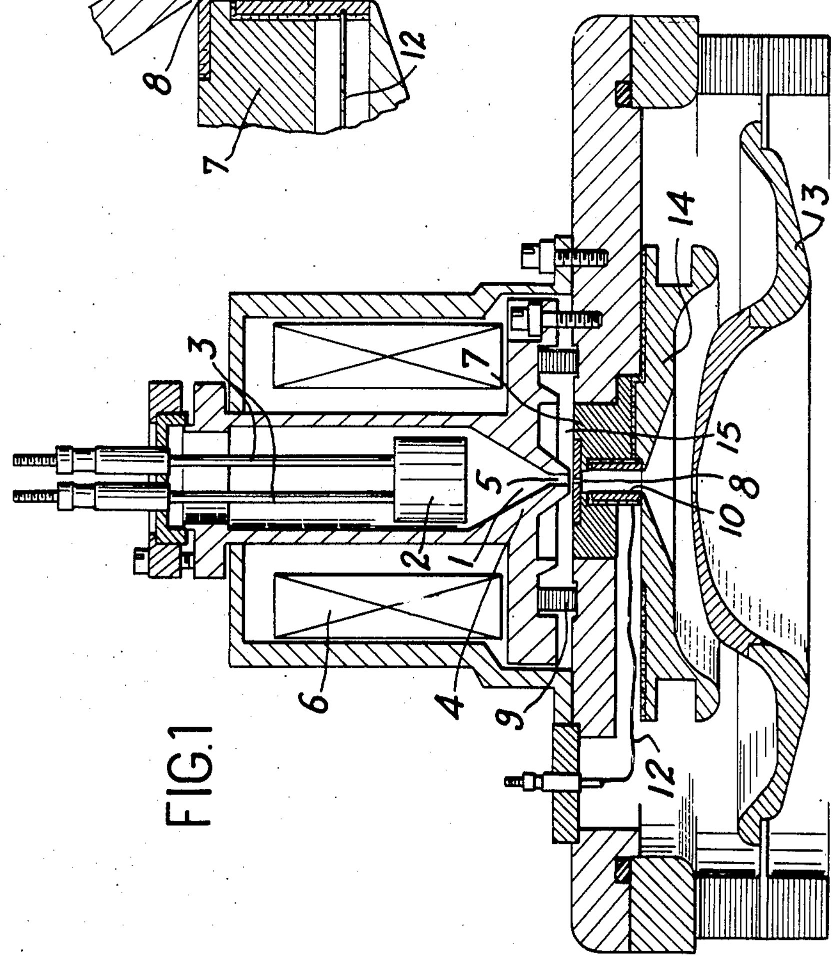


FIG.1

FIG.3

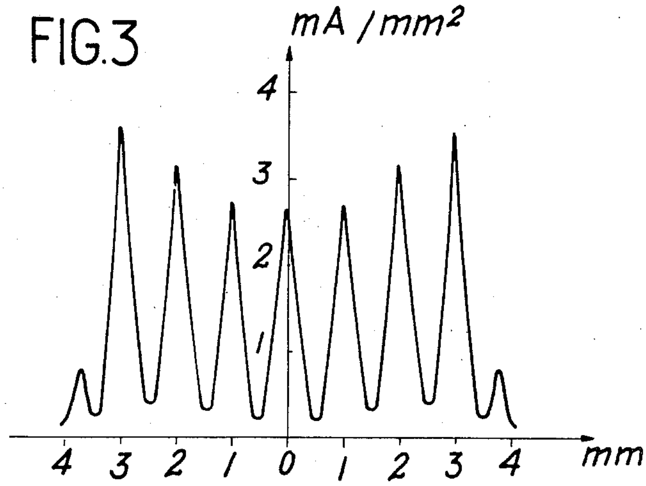
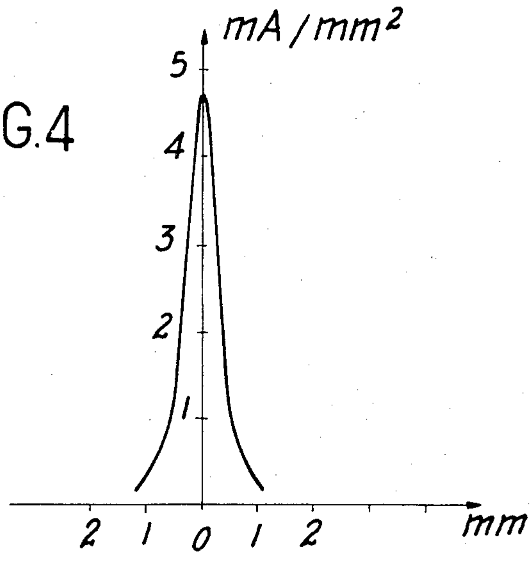


FIG.4



ION SOURCE HAVING A UNIFORM RADIAL DENSITY

This invention relates to an ion source having a uniform radial density.

One of the important parameters to be taken into consideration when constructing an ion source is the number of ions available at the outlet of the source, a desirable objective being to obtain as large a number of ions as possible. These ions are usually accelerated and, in order to reduce the losses of ionized particles, it is accordingly essential to ensure that the beam of ions derived from the source should correspond to predetermined characteristics which have been established as a result of theoretical and experimental studies. In fact, the ion beam must have on the one hand a substantial diameter and on the other hand a uniform radial density at the outlet of the source. A large beam diameter can be obtained by allowing the ion plasma to spread as soon as it has been formed in the ion source. The ions must then be extracted so that they form at the outlet of the source a parallel beam which has a uniform radial density.

Parallel beams of large diameter have been obtained by making use of ion sources of the "duoplasmatron" type in which a high-density plasma of ions and electrons is formed between an electrode and an anode pierced by a hole through which the ions formed are extracted by means of an extraction electrode which is brought to a very high negative electric potential of several tens of kilovolts. At the outlet of the anode hole, a unipotential cylindrical electrode known as a plasma expansion control electrode which is brought to the same potential as the anode permits the expansion of said plasma. However, sources of this type cannot operate satisfactorily if there is no oxidation of the internal surface of the expansion control electrode which results in a certain degree of surface polarization of this latter. Tests carried out with a source of this type, the internal surface of which was coated with a gold film in order to prevent oxidation, have shown that the source was only capable of emitting a beam having a small diameter. Although it has proved feasible to operate sources of this type by means of surface polarization, the operating conditions are erratic and uncertain since this polarization cannot be controlled.

The invention provides a device which meets practical requirements more effectively than comparable devices of the prior art, particularly by virtue of the fact that it is not attended by the disadvantage referred-to above, namely inhomogeneity of radial density of the ion beam.

More specifically, this invention is directed to an ion source having a practically uniform radial density, characterized in that said source comprises an ionization chamber into which the gas to be ionized is introduced, a cathode placed at the center of an intermediate electrode provided with an orifice for the passage of electrons, an anode provided with a hole for the passage of ions, a plasma-expansion control electrode which is electrically insulated from the anode and brought to a negative potential with respect to the anode potential, an ion extraction electrode.

A better understanding of the invention will be gained from the following description of one embodiment of the invention which is given by way of non-

limitative example, reference being made to the accompanying drawings, wherein :

FIG. 1 is a sectional view of the ion source ;

FIG. 2 is an enlarged view showing a portion of the ion source ;

FIGS. 3 and 4 are curves representing the radial density of the ions as a function of the distance from the beam axis as obtained respectively by means of the ion source in accordance with the present invention and by means of a source of the prior art, the extraction electrode being maintained at the same potential in both cases.

The source which is illustrated in FIGS. 1 and 2 corresponds more especially to the production of a proton beam. Hydrogen is accordingly introduced in the chambers **1** and **15** through an orifice which is not shown in FIGS. 1 and 2. The chamber **1** comprises a cathode **2** and its means **3** for supplying electric current. The chamber **1** is delimited by the envelope of a hollow cylinder **4** which terminates at one end in a cone frustum having the same axis as said cylinder and at the other end in a disc provided with two insulated lead-in bushings for the supply of electric current. A large quantity of electrons is discharged from the chamber **1** through an outlet **5** and produces intense ionization within the chamber **15**. A magnetic coil **6** confines the plasma within the zone of the hole **8** of the anode **7** ; said anode is placed at right angles to the axis of the member **4**. A seal **9** of either the toric or cylindrical type and formed of electric insulating material serves to insulate the anode **7** from the chamber **1**. A cylinder **10** which constitutes the expansion control electrode is insulated electrically from said anode **7** by means of an insulator **11**. An electric conductor **12** serves to polarize said cylinder **10** at an electric potential which is different from that of the anode **7** which is usually at zero potential. An extraction electrode **13**, which is polarized at a very high negative voltage, accelerates the ions which are formed. That portion of the ion source which is located downstream of the anode **7** is maintained under a vacuum by means of a vacuum pump which is not shown in FIGS. 1 and 2. The member **14** is an electrode which is connected electrically to the cylinder **10**.

In the case of the proton source which is illustrated in FIGS. 1 and 2, the potentials applied to the different electrodes can be as follows :

— cathode **2** : − 120 V
— anode **7** : 0 V
— expansion control electrode **10** : − 60 V
— electrode **4** : − 60 V
— extraction electrode : − 45 kV.

The means employed for polarizing the portions **4, 7** and **13** are not illustrated in FIGS. 1 and 2.

The principle of operation of the ion source in accordance with the invention can be understood from the following reasoning. If the expansion control electrode **10** is at the same potential as the anode **7** which is usually zero, as is the case with ion sources of the prior art, all the electrons of the plasma, which is formed in the ionization chamber **15**, are collected by the anode **7** and the electrode **10**. These electrons are directed towards the walls of the expansion electrode **10** and carry along the ions which recombine in contact with said electrode. This results in a reduction in the ion density which is available for the extraction of the beam throughout the chamber and this reduction is particularly substantial away from the axis. The radial density of the ion beam thus obtained is then non-uniform.

On the other hand, when the expansion control electrode **10** is polarized at a negative value as in the ion source according to the present invention, the electrons which were initially directed towards the internal wall of the expansion control electrode at a high velocity together with the entrained ions now have a much lower scattering velocity ; this results in an increase in electron density and consequently in ion density as well as uniformity of plasma density.

In FIGS. **3** and **4**, the radial density of the ion beam as expressed in $ma.mm^{-2}$ is represented as a function of the distance to the center of the beam as obtained by means of an ion source respectively in accordance with the invention (as shown in FIG. **3**) and of a known type (as shown in FIG. **4**). These curves are obtained by providing the extraction electrode with an interception plate which is pierced along a diameter with holes having a spacing of 1 mm and a diameter of 0.2 mm. Each pencil beam of ions thus obtained is scanned by means of a slot which is displaced at right angles to the optical axis of the beam. A comparison of the curves of FIGS. **3** and **4** clearly shows the improvements which are provided by the invention : on the one hand, the radial density of the beam is uniform and, on the other hand, the total number of ions is greater, which means that the ion losses have been reduced to a considerable extent.

It is to be understood that this invention is not limited solely to the embodiment which has been described by way of explanation with reference to the accompanying drawings but that this patent also extends to alternative forms of all or part of the arrangements hereinabove described which remain within the scope of equivalent means as well as to all applications of such arrangements. For example, the expansion control electrode has been represented by a cylinder but it remains apparent that the shape of the electrode may be adapted to the desired results.

What we claim is:

1. An ion source having a practically uniform radial density comprising an ionization chamber into which a gas to be ionized is introduced, an intermediate electrode, an anode spaced therefrom and forming with said electrode said ionization chamber, said intermediate electrode having an orifice for the passage of electrons into said chamber, a cathode upstream of said intermediate electrode facing said orifice in said intermediate electrode, said anode being downstream from said intermediate electrode, said anode having an orifice for the passage of ions therethrough, a plasma-expansion control electrode downstream of and electrically insulated from said anode and at a negative potential with respect to said anode and an ion extraction electrode downstream from said control electrode.

2. An ion source according to claim **1**, said expansion control electrode having an internal surface of a material preventing undesirable polarization of the internal surface.

3. An ion source according to claim **1**, said expansion control electrode having an internal surface coated with a gold film.

4. An ion source according to claim **1**, said control electrode having an internal surface at a negative electric potential equal to that of said intermediate electrode.

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