NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF: GP

October 16, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned
U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,311,772

Corporate Source : Electro-Optical Systems

Supplementary
Corporate Source :

NASA Patent Case No.: XNP-03332

Gayle Parker

Enclosure:
Copy of Patent

NASA-HQ

March 28, 1967 R. C. SPEISER ET AL 3,311,772
FOCUSSING SYSTEM FOR AN ION SOURCE
HAVING APERTURED ELECTRODES
Filed May 18, 1964

Fig. 1

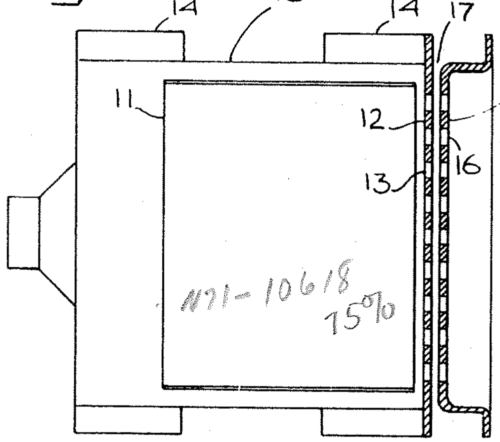
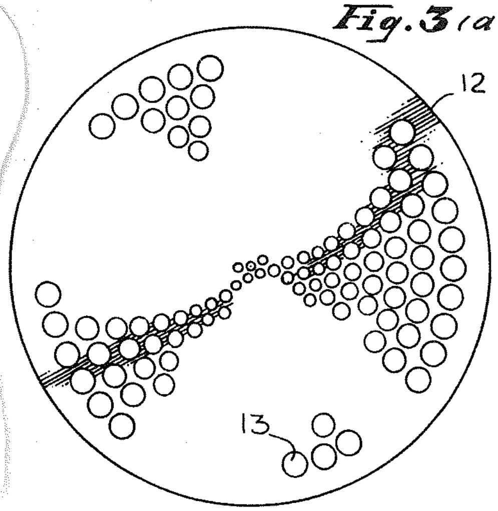
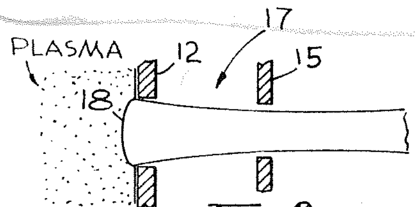


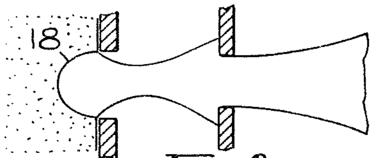
Fig. 3 (a)





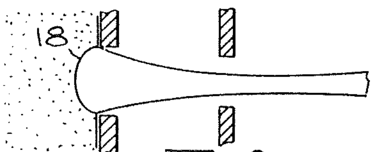
$n = n_o$

Fig. 2 (a)



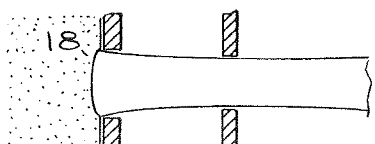
$n \ll n_o$

Fig. 2 (b)



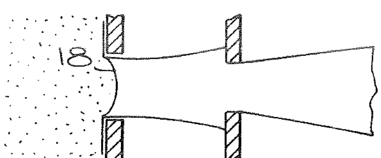
$n < n_o$

Fig. 2 (c)



$n > n_o$

Fig. 2 (d)



$n \gg n_o$

Fig. 2 (e)

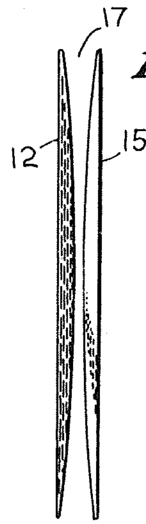
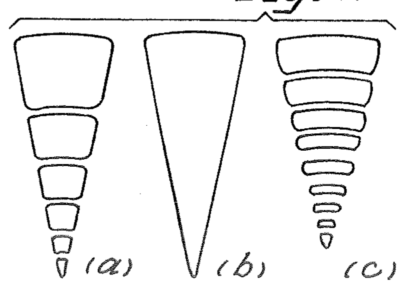


Fig. 3 (b)

Fig. 4



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United States Patent Office

3,311,772
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3,311,772
FOCUSSING SYSTEM FOR AN ION SOURCE HAVING APERTURED ELECTRODES

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Filed May 18, 1964, Ser. No. 368,123
6 Claims. (Cl. 313—63)

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

The present invention relates in general to an improvement in ion sources and more particularly relates to an improved electrode system for ion sources.

A major ion optics problem in gas-discharge ion sources is the non-uniformity of the plasma density across the diameter of the source. If the electrode potentials are adjusted for good focusing from apertures near the center of the source, the arrival rate of ions at the plasma sheaths of the apertures near the periphery of the source will be too low and sheath shapes leading to poor focusing will result.

Accordingly, it is an object of the present invention to provide a more effective ion source through the proper focusing of the ion beams.

It is another object of the present invention to provide an electrode system that will properly focus the ion beams emitted from an ion source notwithstanding the non-uniformity of the plasma density across the diameter of the source.

The abovesaid problem of focusing ions from a plasma whose density has a non-uniform distribution in the sourse has been substantially resolved by means of a new type of electrode system based on a varied geometry concept. More particularly, given the radial plasma distribution of a source, the ion optics can be improved by varying the size of the apertures and gaps of the electrode geometry in such a manner as to provide a perveance per unit area which changes radially in the same way as the ion density in the source. By so doing, substantially the same focusing conditions are then provided at the periphery of the source as at the center for the radially decreasing plasma densities encountered.

The apertures may take the form of circular or pear-shaped holes or may even have a slit configuration, or any other configuration for that matter, the only basic requirement here being that the apertures open wider, that is to say, increase in size with the radius. As to the gap or spacing between the screen and accelerating electrodes, the gap or spacing is varied in the manner desired by providing the electrodes with an appropriate curvature that is related to the ion density distribution in the plasma.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawing in which an embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only and is not intended as a definition of the limits of the invention.

FIGURE 1 is a schematic diagram that generally illustrates an electron bombardment ion source;

FIGURES 2(*a*)–2(*e*) are a series of figures that respectively illustrate the different plasma meniscus and focusing properties that may be encountered;

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FIGURES 3(*a*) and 3(*b*) are respectively front and side views of a distributed geometry electrode system according to the present invention; and

FIGURES 4(*a*)–4(*c*) present examples of alternative aperture geometries that may be used in an electrode system according to the present invention.

Considering now the several figures in the drawing wherein like or similar parts or elements have been similarly designated, reference is made first to FIG. 1 wherein is shown an ion source in which an electrode system according to the present invention may be utilized. As depicted, the ion source basically includes a cylindrical arc chamber **10** with a cylindrical anode **11** supported within it. The anode is operated at a potential that is positive with respect to the end plates which are at cathode potential. One of the end plates, designated **12**, is the anticathode or screen electrode and has apertures **13** through it. Magnet coils **14** set up a magnetic field parallel to the axis of the chamber. The whole chamber is run at a high positive potential V+ and an accelerating electrode **15** is run at a negative potential, the accelerating electrode having apertures **16** through it that match the apertures in the screen electrode Ions diffusing to the plasma sheath at the screen electrode can be accelerated and focused into beams by the fields across the accelerating gap **17** and through the apertures. These beams are then neutralized by the injection of electrons from an emitter at, or close to, ground potential. Under these conditions the exhaust becomes a plasma at a potential close to ground.

The negative potential on accelerating electrode **15** provides the barrier necessary to prevent the neutralizing electrons from going back into the source. Ions are accelerated through a voltage drop of V+ plus V− and decelerated through a potential V− to a velocity corresponding to the energy $eV+$.

It will be noted from the figure that in the typical ion source electrode system, the spacing **17** between the screen and accelerating electrodes is a constant. It will further be noted from the figure that apertures **13** and **16**, aside from being in registration with each other, are of constant size or diameter. As a result of these conditions and the fact that the plasma density is non-uniform across the diameter of the ion source, improper beam focusing is generally experienced as heretofore mentioned and as is illustrated in FIGS. 2(*a*)–2(*e*) to which reference is now made.

Generally speaking, during the process of beam-formation from the plasma, ions move toward the boundary of the plasma as a result of density and potential gradients, the number actually reaching the boundary being approximately proportional to the area of this plasma boundary surface or meniscus **18**. This area varies by a factor of 2 over the extremes of a planar to a hemispherical meniscus stretched across the same aperture. Moreover, the requirement that the field be continuous across the boundary between the plasma and accelerating region dictates that the field at the source side of screen electrode **12** be very close to 0. If the ion energies in the plasma are small compared to the energy to which they will be accelerated, the situation is similar to that of a space-charge limited ion current from a surface whose shape matches the sheath boundary. If the ion generation rate decreases or the gap voltage increases, the surface of the plasma moves away from accelerating electrode **15** and changes the ion trajectories as well as the total ion current. The position of plasma meniscus **18** is, therefore, one of the most important elements of the electrode geometry. It is not a fixed surface but, rather, its position is dependent, among other things, upon the plasma, the plasma density and the accelerating voltages. Because of the plasma density distribution at the screen electrode, the beam intensity is not uniform over the entire source area and, therefore, optimum meniscus positioning has been extremely difficult to achieve and this, as was previously mentioned, has in turn led to poor focusing.

Examples of several different kinds of beam focusing that are usually encountered with present-day electrode systems, as, for example, the electrode system shown in FIG. 1, are presented in FIGS. 2(*a*)–2(*e*), wherein the letter n stands for the ion density at any point in the plasma, that is to say, the number of ions per unit of volume in the plasma, and wherein n_0 represents the normal or what is considered the optimum level of ion density as it was defined above. Where n is greater than n_0, then in that kind of situation meniscus **18** moves closer to gap **17**. On the other hand, where n is less than n_0, then the meniscus is found to move away from the gap. Proper positioning of the meniscus is obtained, therefore proper beam focusing is also obtained, where $n=n_0$. Thus FIG. 2(*a*) illustrates the case where $n=n_0$, namely, the case in which proper beam focusing is obtained. FIGS. 2(*b*)–2(*e*), on the other hand, are illustrative of poor focusing situations, namely, where n is either greater than or very much greater than n_0 or else less than or very much less than n_0. As previously indicated, if too many ions are approaching the plasma sheath, this surface moves closer to the accelerating electrode which decreases the concave sheath area and slightly decreases the ion arrival rate. It can also be seen from the figures that for higher ion generation rates, the meniscus will actually become convex and produce a divergent beam with serious electrode interception.

An electrode system which, in accordance with the present invention, has a distributed geometry for the purpose of producing proper beam focusing across the entire ion source is illustrated in FIGS. 3(*a*) and 3(*b*). A view of the face of screen electrode **12** is presented in FIG. 3(*a*) and, as shown therein, the size of apertures **13** is scaled with the apertures of smallest diameter being located at the center of the electrode and the apertures having the largest diameter being located along and following the periphery of the electrode. Between the two extremes, the apertures are graduated in size, as shown in the figures. In view of the fact that the apertures through the screen electrode and the apertures through the accelerating electrode, namely, apertures **13** and **16**, are in registration with each other, it will be recognized that the appearance of the two electrodes are substantially the same, or, stated differently, the frontal view in FIG. 3(*a*) is applicable to both electrodes. A side view of screen and accelerating electrodes **12** and **15**, respectively, showing them mounted in face-to-face relationship is illustrated in FIG. 3(*b*). It can be seen from this figure that the two electrodes are saucer-shaped with the convex surfaces thereof facing each other. As a result, gap **17**, like the electrode apertures, is non-uniform with the spacing between the electrodes increasing with distance from their axis. In other words, the electrodes are spaced closer together near their centers than they are near their peripheries. As was indicated earlier, by thusly varying the size of the apertures and of the gap, a perveance per unit area is provided which changes radially in the same way as the ion density in the source, thereby producing good beam focusing of the type shown in FIG. 2(*a*).

Although the apertures through the electrodes of FIG. 3 are circular in shape, it will be recognized by those skilled in the arts that the electrode geometry is not limited in this manner but, rather, that it may have other aperture configurations with equally good if not better effect. Accordingly, by way of example, several other types of aperture configurations are illustrated in FIGS. 4(*a*)–4(*c*). In

FIG. 4(*a*), the apertures are shown to be a plurality of pear-shaped openings with the wider part of each opening being more distant from the electrode axis than the narrower portion. In FIG. 4(*b*), the opening is shown to have the shape of an isosceles triangle, with the apex of the triangle at the electrode axis and the base of the triangle at the circumference of the electrode. Finally, in FIG. 4(*c*), the apertures are shown to be in the form of slits that follow an arc of a circle and that become progressively longer as their radius of curvature increases. These are but a few examples and, therefore, still other aperture configurations may be utilized according to need.

Although a particular arrangement of the invention has been illustrated above by way of example, it is not intended that the invention be limited thereto. Accordingly, the invention should be considered to include any and all modifications, alterations, or equivalent arrangements falling within the scope of the annexed claims.

Having thus described the invention, what is claimed is:

1. An electrode system for an ion source in which the plasma density is non-uniform across the diameter of said source, said electrode system comprising: screen and accelerating electrodes positioned in face-to-face relationship, said electrodes having apertures therethrough that are in registration with each other, said apertures varying in size in accordance with the radial displacement thereof from the center of the electrode and inversely as the plasma density.

2. An electrode system for an ion source in which the plasma density is non-uniform across the diameter of said source, said electrode system comprising: screen and accelerating electrodes positioned in face-to-face relationship in such a manner that the spacing therebetween varies inversely as the plasma density, said electrodes having apertures therethrough that respectively are in registration with each other and whose sizes vary in accordance with the radial displacement thereof from the center of the electrode and inversely as the plasma density.

3. The electrode system defined in claim **2** wherein said electrodes are saucer-shaped with the convex surfaces thereof being face-to-face, and wherein said apertures are circular, the diameters thereof changing inversely as the plasma density.

4. The electrode system defined in claim **2** wherein said electrodes are saucer-shaped with the convex surfaces thereof being face-to-face, and wherein said apertures are pear-shaped.

5. The electrode system defined in claim **2** wherein said electrodes are saucer-shaped with the convex surfaces thereof being face-to-face, and wherein said apertures are slits that extend in a peripheral direction around the electrodes.

6. An electrode system for an ion source in which the plasma density decreases with distance from the source axis, said electrode system comprising: a pair of saucer-shaped metal plates positioned with their convex surfaces in face-to-face relationship, said plates having substantially registering apertures therethrough whose size corresponds with their distance from the centers thereof; and means for applying a voltage between said plates to focus the ion beams passing therethrough.

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