United States Patent [19]
Pleshivtsev et al.

[11] 3,798,488
[45] Mar. 19, 1974

[54] PLASMA SOURCE OF CHARGED PARTICLES

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[22] Filed: **July 28, 1971**

[21] Appl. No.: **166,694**

[52] U.S. Cl. **313/231,** 313/DIG. 8
[51] Int. Cl. **H01j 61/28**
[58] Field of Search .... 313/231, DIG. 8

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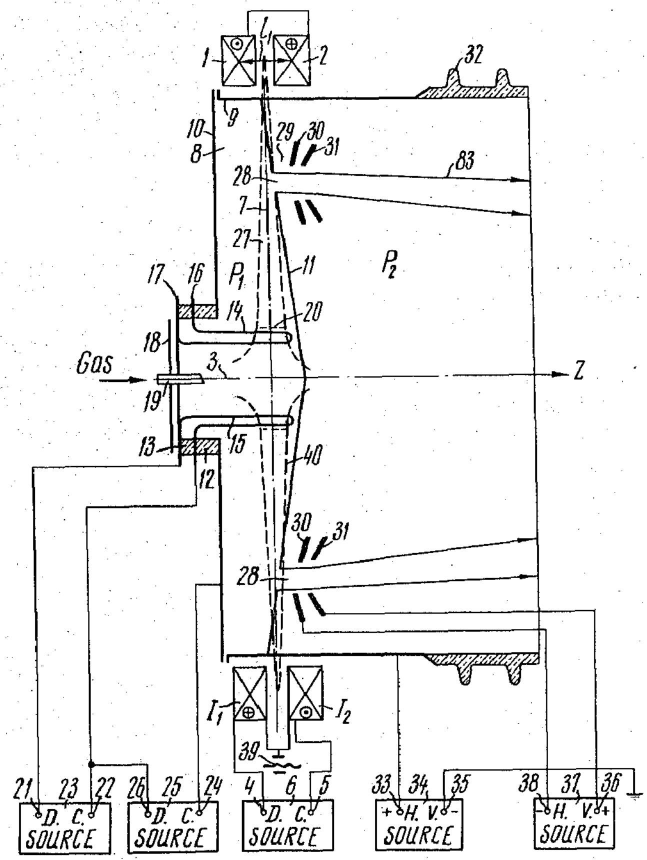
Primary Examiner—Roy Lake
Assistant Examiner—James B. Mullins
Attorney, Agent, or Firm—Holman & Stern

[57] **ABSTRACT**

A plasma source of charged particles is provided by an arrangement having two solenoids mounted on a single axis and connected in opposition in a gas-discharge chamber to set up a magnetic field increasing along the radius; the arrangement also includes two electrodes in the gas-discharge chamber one of which made in the shape of a disk having at least one emission slit placed approximately on the median surface of the magnetic field, and a system of charged perticle extraction, acceleration and focusing.

21 Claims, 12 Drawing Figures



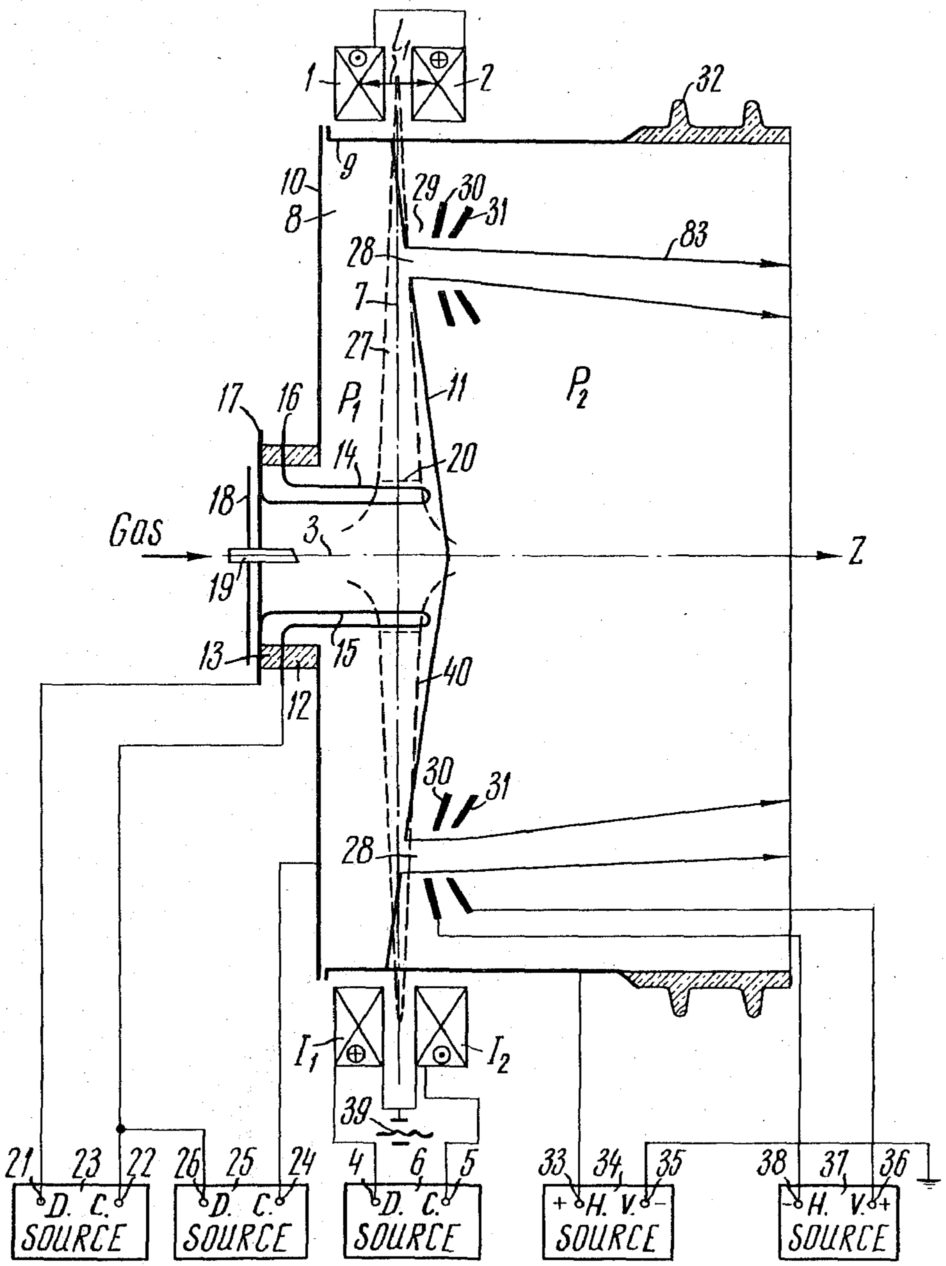


FIG. 1

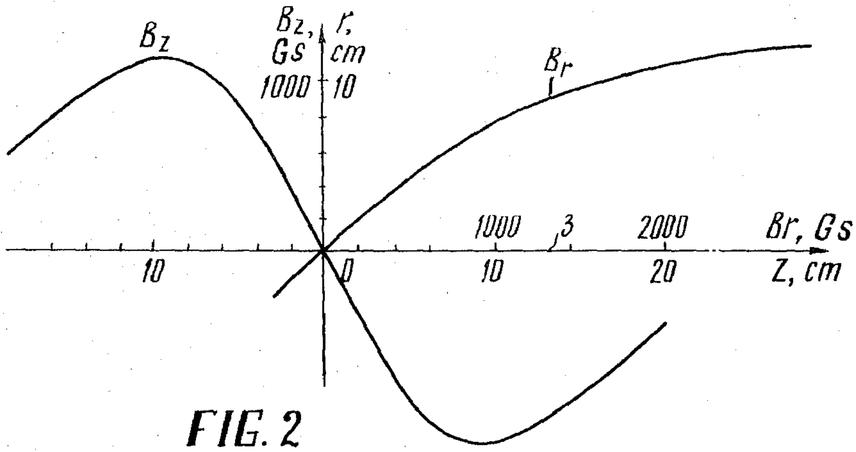


FIG. 2

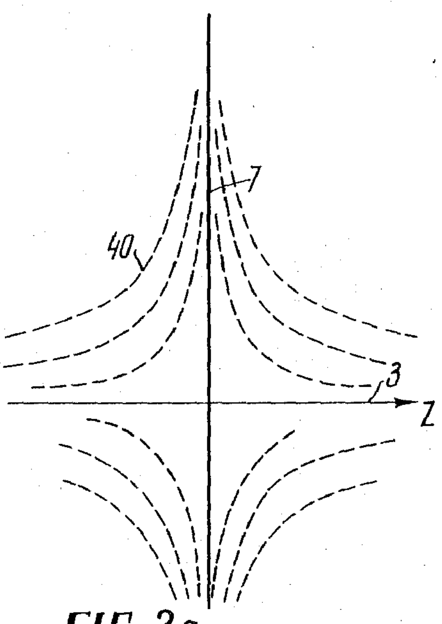


FIG. 3a

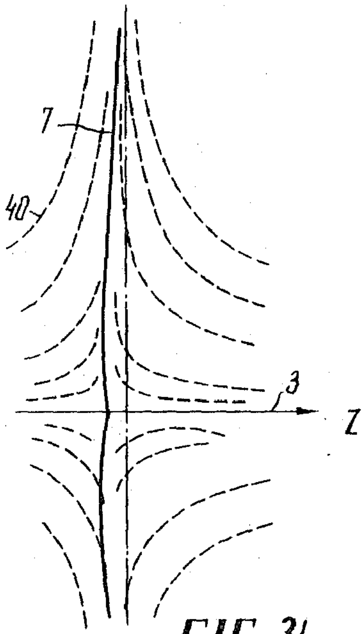


FIG. 3b

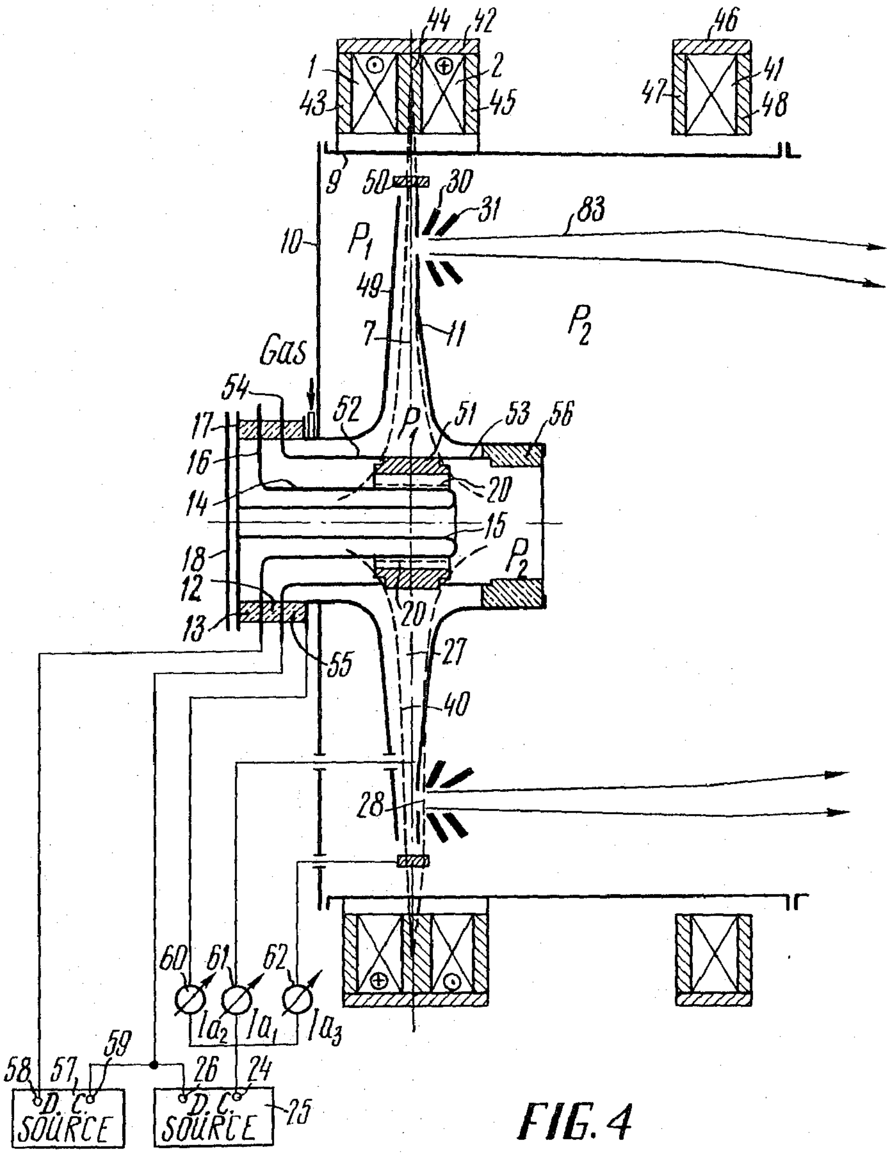

44
42
46
1
2
43
45
47
41
48
9
50
30
31
83
10
P_1
49
7
11
P_2
Gas
54
52
51
53
56
17
16
14
15
20
18
12
13
55
20
27
40
28
60
61
62
Ia_2
Ia_1
Ia_3
58
57
59
26
24
D.C.
SOURCE
D.C.
SOURCE
25

FIG. 4

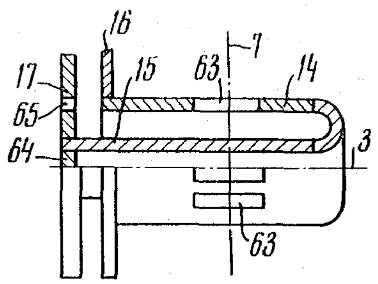


FIG. 5a

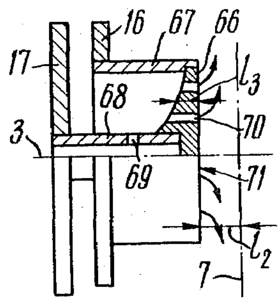


FIG. 5b

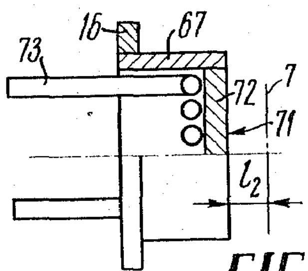


FIG. 5c

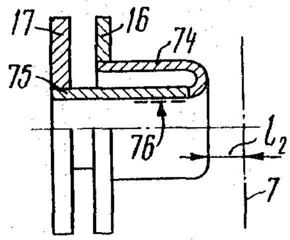


FIG. 5d

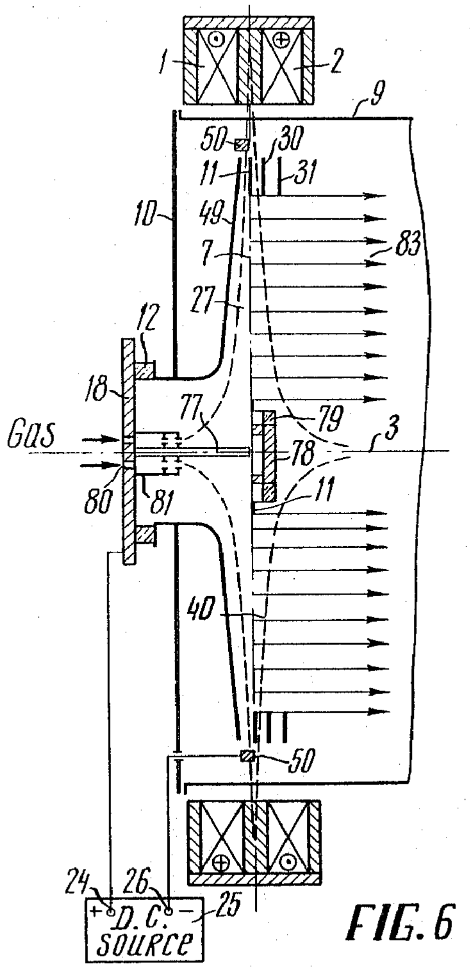

1
2
9
50
30
31
11
10
49
7
83
27
12
18
77
79
Gas
3
78
80
81
11
40
50
24
26
25
+ D.C. −
SOURCE

FIG. 6

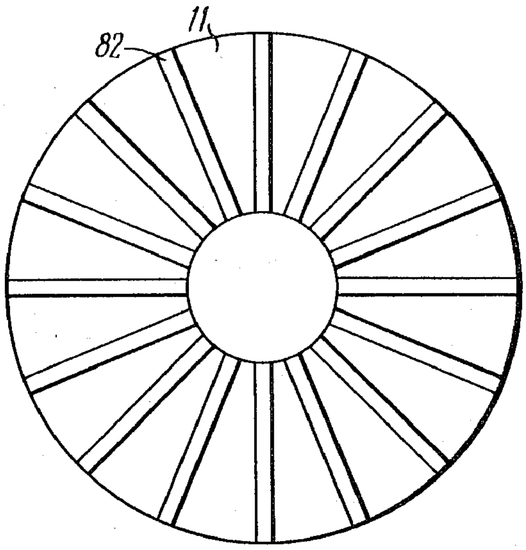
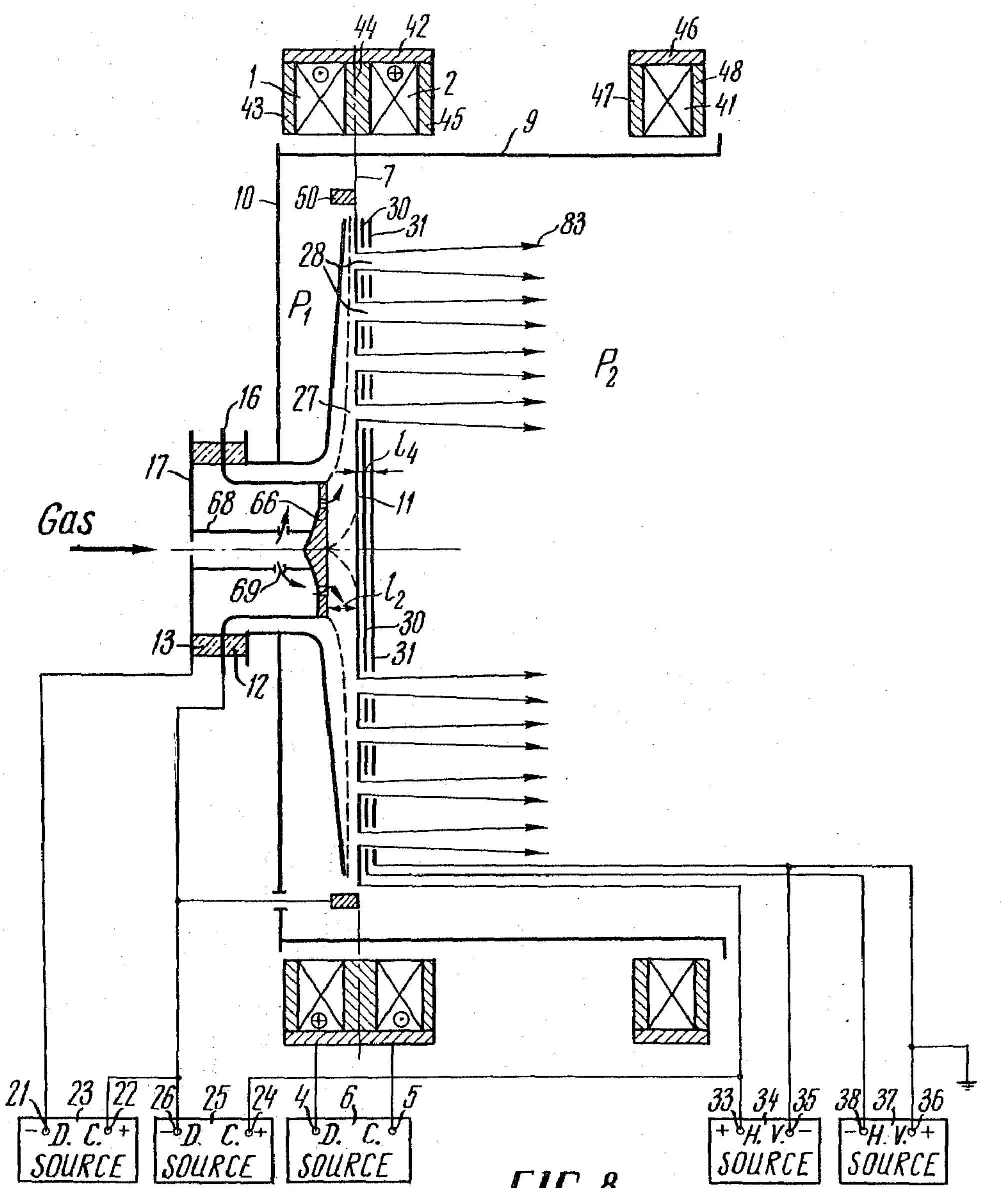

11
82

FIG. 7


44
42
46
1
43
2
45
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41
9
7
10
50
30
31
83
28
P1
P2
16
27
17
l4
68
66
11
Gas
69
l2
30
13
31
12
21
23
22
D. C.
SOURCE
26
25
24
D. C.
SOURCE
4
6
5
D. C.
SOURCE
33
34
35
H. V.
SOURCE
38
37
36
H. V.
SOURCE

FIG. 8

PLASMA SOURCE OF CHARGED PARTICLES

The invention relates to the field of charged particle acceleration and electron- and ion-beam engineering, and, more particularly, it is concerned with plasma sources of charged particles such as ions, fast atoms and electrons, designed for use in charged particle accelerators, experimental thermonuclear installations and reactors, ion motors, electron and ion guns and other devices of a similar nature.

It is known to use plasma sources of charged particles, comprising two electrodes placed in a gas-discharge chamber to set up an expanding arc discharge, a solenoid to set up a magnetic field which is instrumental in extracting plasma out of the gas-discharge chamber with a view to obtaining a larger cross-sectional area of the gas-discharge plasma, and a system of electrodes for the extraction, acceleration and focusing of charged particles.

A disadvantage of the above charged particle source with an expanding arc discharge consists in that it provides inadequate current densitites of the charged particles from the large plasma emission areas on account of the fact that, as the distance from the source axis grows, the concentration of charged particles in the source diminishes, because of the increase in the area of the plasma-confining magnetic flux.

Another disadvantage of this prior art device plasma source consists in that charged particles are extracted from the plasma boundary which is in all cases characterized by the presence of an axial component of the magnetic field which imparts azimuthal velocities to the particles with the consequent deterioration of the focusing of the charged particle beam.

An object of the present invention is to provide a plasma source of charged particles which will induce a radial arc discharge and where plasma concentration will be independent of the distance to the source axis, which will permit extracting charged particles from a large-area plasma surface with a high concentration of charged particles, and which will set up a magnetic field of such a shape as to prevent the axial component of the magnetic field from arising on the boundary of the charged particle emitting plasma. This will obviate the azimuthal components of the charged particle velocities being the magnetic field.

With this object in view, in accordance with the present invention the plasma source of charged particles is provided with a second solenoid mounted on the extension of the axis of the first solenoid and connected in opposition with the former, whereas one of the arc-discharge electrodes is made in the shape of a disk having at least one emission slit and disposed approximately on the median surface of the magnetic field.

It stands to reason to equip the plasma source of charged particles with yet another solenoid mounted on the extension of the axis of the second solenoid and performing the function of a focusing system.

It is expedient to protect the solenoids with a soft-iron shield.

It is desirable that the solenoids could be shifted along their axes.

It is preferable to use the disk-like electrode as an anode in the form of a funnel with its mouth turned towards the median surface; the other electrode serves as a cathode.

It is desirable that the plasma source of charged particles be provided with a third electrode serving as an anti-cathode and made in the shape of a ring on the median surface coaxially with the anode.

It is desirable to provide the plasma source of charged particles with a second anode made similar to the first one and symmetrical to the former with respect to the median surface.

It is also desirable to provide the plasma source of charged particles with yet another anode in the shape of a ring positioned on the median surface coaxially to the disk-like anodes.

The second electrode, which serves as a directly heated cathode, may be made in the form of two coaxial cylinders in coaxial alignment with respect to the disk-like anodes and passing through the central holes in the latter.

In this case, it is desirable to apply emissive coating to the outer surface of the external cylinder in an area adjacent to the median surface.

It is also possible to provide the external cylinder in an area adjacent to the median surface with longitudinal slits uniformly spaced along the circumference of the cylinder.

Besides, the second electrode, if it is an indirectly heated cathode, may be made in the shape of a ring aligned coaxially with the anode on the median surface, made of a material with a high emissive power and providing uniform emission over the entire working area of the cathode, and equipped with a device for heating the ring.

The second electrode, if it is a directly heated cathode, may be made in the shape of a disk with a cross-section varying along the radius, which provides for uniform emission of electrons over the entire surface of the disk, and aligned coaxially with the disk-like anodes at such a distance from the median surface which provides for plasma extration into a region directly adjacent to the median surface.

The second electrode, if it is an indirectly heated cathode, may be made in the shape of a disk coaxial with the dis-like anodes at such a distance from the median surface which distance provides for plasma extraction into a region directly adjacent to the median surface, and equipped with a device for heating the disk.

It is also possible to make the second electrode, if it is a hollow cathode, in the form of two coaxial tubes connected at one end, aligned coaxially with the disk-like anodes at such a distance from the median surface that provides for the ejection of electrons from the inner tube and plasma formation in a region adjacent to the median surface.

The second electrode may be also made in the shape of a ring aligned on the median surface coaxially with the disk-like anode in the vicinity of the emission slit of said anode which in this case is circular.

It is expedient in the plasma source of charged particles to have the disk-like electrode function as a cold cathode and make it in the shape of a funnel with the mouth turned towards the median surface, the second electrode — as an anode and make it in the shape of a rod coaxial with the disk-like electrode and pressed against the median surface with its end, and provide the source with a third electrode to serve as a cold cathode made similar to the first electrode and aligned symmetrically with said first cathode with respect to the median surface, and with a fourth electrode, also a cold cathode, made in the shape of a ring aligned on the median surface coaxially with the disk-like electrodes.

The emission slits may be made in the shape of concentric circles uniformly spread about the entire surface of the disk-like electrode.

The emission slits may be also made in a radial pattern and spread uniformly about the entire surface of the disk-like electrode.

It is preferable that the system of electrodes for the extraction, acceleration and focusing of charged particles be made in the form of two disk-like electrodes with circular concentric slits on the outside of the disk-like electrode to provide a discharge, at a distance ensuring extraction and focusing of hollow beams of charged particles toward the axis of the solenoids, as well as ensuring the dielectric strength of the system of electrodes for the extraction, acceleration and focusing of charged particles; the circular slits of the system of electrodes must be aligned in opposition with the circular emission slits of the discharge-producing electrodes.

It is also expedient to make the system of electrodes for the extraction, acceleration and focusing of charged particles in the form of two disk-like electrodes with radial slits uniformly spread about the entire surface of said electrodes, positioned on a side of the disk-like arc-discharge electrode external with respect to the median surface at a distance providing for the extraction and focusing of charged particles towards the axis of the solenoids, as well as the electric stability of the system of electrodes for the extraction, acceleration and focusing of particles; the slits of the extraction system of electrodes must be opposite the radial emission slits of the discharge-producing electrodes.

BRIEF DESCRIPTION OF DRAWINGS

Hereinafter the invention is illustrated by specific examples and drawings of which:

FIG. 1 is the diagram of a plasma source of ions with a single circular emission slit and with a coaxial directly heated cathode, according to the present invention;

FIG. 2 illustrates curves of variation of the axial component of the magnetic field along the axis of the solenoids, and of the radial component of the magnetic field versus radius, according to the present invention;

FIG. 3*a* illustrates the pattern of the magnetic field at equal currents in the solenoids;

FIG. 3*b* shows a pattern similar to that in 3*a* at different currents through the solenoids;

FIG. 4 is a diagram of a plasma source of ions with three soft iron-shielded solenoids, according to the invention;

FIG. 5*a* is a coaxial directly heated cathode used in the present invention;

FIG. 5*b* is a disk-like directly heated cathode, used in the invention;

FIG. 5*c* is a disk-like indirectly heated cathode used in the present invention;

FIG. 5*d* is a hollow directly heated cathod used in the present invention;

FIG. 6 is a diagram of a plasma source of ions with a plurality of radial emission slits, according to the present invention;

FIG. 7 is a disk-like electrode with radial emission slits uniformly distributed about its surface, according to the present invention, and

FIG. 8 is a diagram of a plasma source of ions with a plurality of circular emission slits, according to the present invention.

FIG. 1 shows a plasma source of ions containing solenoids **1** and **2** serving to provide a radial discharge. Solenoid **2** is mounted a centre distance l_1 from solenoid **1** on the extension of its axis **3**. Solenoids **2** and **1** are electrically connected in opposition to terminals **4** and **5** of the power supply **6**. Currents I_1 and I_2 through the windings of solenoids **1** and **2** set up opposition magnetic fields which, by interaction, form a magnetic field of the so-called cusp-geometry. The axial components of the magnetic fields of solenoids **1** and **2** cancel out, and between solenoids **1** and **2** there emerges a median surface **7** where the axial component of the resultant magnetic field is equal to zero.

A radial discharge is created in gas-discharge chamber **8**, made of non-magnetic material and formed by cylinder **9**, flange **10** closing one of the ends of cylinder **9**, and disk electrode **11** forming chamber **8** on the other side. Electrode **11** is shaped like a funnel, almost conforms to the median surface **7**, and is placed in the immediate proximity thereof. Thereby a condition is ensured which permits avoiding the azimuthal velocities of the ions extracted from the boundary of the emitting plasma placed in a strong radial magnetic field, but with the axial component of the magnetic field equal to zero.

An indirectly heated cathode, which is made up of two coaxially positioned tantalum cylinders **14** and **15** welded together at one end is connected to flange **10**, made of non-magnetic material, for instance, stainless steel, via insulators **12** and **13**. On the other side, tantalum disk-shaped conductors **16** and **17** are welded to cylinders **14** and **15**.

The coaxial alignment of cylinders **14** and **15** helps eliminate the interferences from the magnetic fields set up by the cathode-heating currents.

Conductors **16** and **17** have flange **18** with soldered tube **19**, which serves to inject gas into gas-discharge chamber **8** through a gas-injection system not shown in FIG. 1. Pressure P_1 of the working gas whose ions it is required to obtain, is built up in gas-discharge chamber **8**.

Where median surface **7** intersects cylinder **14**, the cylinder surface has emissive coating **20**, say of lanthanum hexaboride which is an excellent electron emitter. For cathode heating, conductors **16** and **17** are connected to terminals **21** and **22** of supply source **23**.

Cylinder **9**, flange **10** and disk electrode **11** are connected to positive terminal **24** of source **25** whose negative terminal **26** is connected to cylinder **14**.

Such an arrangement ensures an ignition of a radial discharge in region **27** immediately adjacent to median surface **7**.

Electrode **11** has an emission slit **28** shaped like a ring coaxial with solenoids **12**. The area of emission slit **28** may be chosen to be sufficiently large. For example, at a mean radius of circular slit **28** equal to 7 cm, the area of the emission slit is not less than 10 cm^2.

Through slit **28**, plasma may diffuse from region **27** to ion-acceleration region **29** where pressure P_2 amounts to 10^{-5} to 10^{-6} mm Hg.

On the outside of electrode **11** are accelerating disk electrode **30** and earthed electrode **31** having circular slits, the mean radii of the circular slits of electrodes **11**, **30** and **31** being equal. Electrodes **30** and **31** are insulated from electrode **11** and region **27** by insulator **32.** Through the central hole in insulator **32,** gas is pumped out of region **27** and acceleration region **29** by vacuum pumps not shown in FIG. **1.**

For the purposes of extraction, acceleration and focusing of ions, disk electrode **11** is connected to positive terminal **33** of high-voltage source **34.**

Electrode **31** is connected to negative terminal **35** of high-voltage source **34** and to earthed positive terminal **36** of high-voltage source **37.** Accelerating electrode **30** is connected to negative terminal **38** of high-voltage source **37.**

For the purposes of extraction, acceleration and focusing of electrons, disk electrode **11** is connected to negative terminal **35** of high-voltage source **34.** Electrodes **30** and **31** are connected to earthed positive terminal **33** of high-voltage source **34.**

Solenoids **1** and **2** are provided with device **39** whereby they can move along axis **3** which assits in deciding conditions conducive to high ion currents. Device **39** may be composed, for instance, of guides and a pair of screws.

FIG. **2** shows the curve of variation of the radial component Br of the summary magnetic field of solenoids **1** and **2** increasing with radius, and the curve of variation of the axial component Bz of the same magnetic field along axis **3** of the solenoids.

The shape and alignment of magnetic force lines **40** obtained at an equality of ions I_1 and I_2 and identity of solenoids **1** and **2,** are shown in FIG. *3a.* In this case median surface **7** is a plane which coincides with the plane of symmetry of solenoids **1** and **2.**

In the case of current I_2 being, say, larger than current I_1, the shape and alignment of magnetic force lines **40,** as well as the geometry and position of median surface **7,** vary, as shown by FIG. *3b.*

In this case median surface **7** assumes the shape of a concave disk conducive to the formation of a beam of ions, if a radially burning discharge is set up along median surface **7.**

FIG. **4** gives another version of a plasma source of ions, which, as against the one described above, includes a third solenoid **41.** All the three solenoids: **1, 2** and **41** are softiron-shielded, for instance, in "Armco" iron. The shield of solenoids **1** and **2** consists of cylinder **42** and disks **43, 44** and **45** with central holes. The shield of solenoid **41** consists of cylinder **46** and disks **47** and **48** with central holes. In the given version of an ion source, there are three electrodes: **11, 49** and **50,** which serve as anodes.

Disk electrode **11** shaped as a funnel has a circular emission slit **28.**

The second anode **49** is designed just like anode **11** and positioned symmetrically with respect to anode **11** about the median surface **7.**

The third anode **50** is shaped like a ring on median surface **7** which concentrically encloses disk-shaped anodes **11** and **49.**

In order to measure the azimuthal distribution of the radial discharge current, circular anode **50** may be cut into a number of isolated sections.

Anode **49** is made of stainless steel and welded to flange **10.** Anodes **11, 49** and **50** have grooves in which cooling water circulates. The indirectly heated cathode is shaped like ring **51** made, for instance, of lanthanum hexaboride. The emitting surface of ring **51** is divided into two symmetrical parts by median surface **7.**

Ring **51** is fixed with tubes **52, 53,** flange **54** and insulators **55** and **56** coaxially with anodes **11, 49** and **50.** The connections between ring **51** and anodes **11** and **49** are sufficiently airtight as to provide a drop of pressure P_1/P_2 of the order of 10^4 times.

The device for heating ring **51** is made of two coaxial tantalum cylinders **14** and **15** welded together at one end. At the other end, these are welded to disk-shaped tantalum conductors **16** and **17.** In region **27** adjacent to median surface **7,** the outer surface of cylinder **14** has lanthanum hexaboride emissive coating **20.** The use, as an electron emitter, of lanthanum hexaboride with its very high emissivity allows of radically cutting down the cathode power consumption.

Ring **51** is heated by electron bombardment. The electrons emitted by emissive coating **20** of the heater of ring **51,** are accelerated by an electric field created by the 0.5–2 - Kv voltage supplied by source **57.** For this purpose, the negative terminal **58** of the source is connected to cylinder **14,** whereas positive terminal **59** is connected to ring **51.**

As a short cut to conditions conducive to high ion currents, anodes **11, 49** and **50** are connected to terminal **24** of source **25** through discharge-current measuring elements **60,61** and **62.**

The cathodes of a plasma ion source, depending on different requirements: design, technical and technological, may be produced in the following versions.

FIG. *5a* shows a directly heated cathode similar to that given in FIG. **1,** except that outer cylinder **14** in region **27** adjacent to median surface **7,** has a number of longitudinal slits **63** uniformly distributed along the circumference of cylinder **14.** These serve to provide uniform gas distribution in region **27** where the radial gas discharge is created. In order to ensure gas flow between cylinders **14** and **15,** the end of cylinder **15** is closed with disk **64,** and the gas is supplied through holes **65** in conductor **17.** Such a cathode design is conducive to the localization of the electron emission region as well as to the azimuthal homogeneity of the radial discharge.

FIG. *5b* shows a directly heated cathode shaped like disk **66** with a variable cross-section. Disk **66** is welded on its outer surface with cylinder **67** to which a conductor **16** is welded.

Tube **68** to which conductor **17** is welded is fixed in the centre of disk **66.** For gas inlet and uniform distribution about the entire surface of disk **66,** tube **68** has holes **69,** whereas disk **66** has holes **70.** Emitting surface **71** of disk **66** is set a distance l_2 from median surface **7,** which provides for plasma extraction into region **27** immediately adjacent to the median surface **7.**

Thickness l_3 of variable cross-section disk **66** must vary approximately obeying the following relation:

$$l_3 = S/2\pi r \qquad (I)$$

where

S — concentric cross-section of the disk,

r — distance from the disk axis.

For technical and technological considerations, it seems more feasible to manufacture an indirectly heated disk cathode, as shown in FIG. *5c.* Here disk **72** is of constant thickness and is heated by heating device **73.**

To obtain plasma with a high concentration of charged particles, use can be made of a hollow cathode made up of two coaxial tubes **74** and **75** connected with each other at one end. Such a cathode is to be positioned coaxially with solenoids **1** and **2** at a distance l_2 from median surface **7**, as shown in FIG. 5*d*. Electrons are emitted from region **76** of inner tube **75**.

The cathodes shown in FIG. 5*b*, *c* and *d*, can be best used when emission slits **28** are uniformly arranged over the surface of electrode **11** (FIG.1).

If it is required to have a single hollow beam of charged particles, one will be well-advised to use a cathode shaped like a ring similar to ring **51** (FIG. 4), but having a diameter approximately equal to that of circular slit **28** in the first electrode **11**.

The electrons emitted by the cathodes can be utilized more efficiently if made to oscillate between the cathode and electrode **51** in region **27** adjacent to median surface **7**. The proper geometry of the electrodes is given in FIG. **4**. Electrode **50** is to be disconnected from the positive terminal **24** of source **25** and connected to negative terminal **26** of the same source, thereby making electrode **50** perform the function of an anticathode. The cathode may look like in FIG. 4, 5*a*, *b*, *c* and *d*.

If the ion source gives off microsecond and millisecond pulses, a cold cathode may be employed thereby saving power otherwise needed for electron emission.

The design of an ion source with a cold cathode is given in FIG. **6**. The first electrode of gas-discharge chamber **8**, which is an anode, is a thin rod **77** mounted on axis **3** and having one end pressed against median surface **7**. The second electrode of gas-discharge chamber **8** is a cold cathode made up of two disks **11** and **49** shaped as funnels with the mouths towards median surface **7** and aligned symmetrically with respect to it. Electrode **11** can be made as a flat disk with a central hole, as shown in FIG. **6**. Electrode **50** in the shape of a ring positioned on median surface **7** coaxially with electrodes **11** and **49**, also serves as a cold cathode. To prevent parasitic or secondary discharge along the axial component of the magnetic field, there is a disk **78** fixed to electrode **11** with the help of insulator **79** in the shape of a ring. Anode rod **74** is fixed to flange **18** having gas injection holes **80**. Cylinder **81** is also fixed to flange **18** to supply gas to region **27** of the radial gas-discharge burning.

Positive terminal **24** of source **25** is connected to anode rod **77**, whereas negative terminal **26** of this source is connected to electrodes **11, 49** and **50**.

One of the conditions conducive to high values of current of charged particles is the use of a slitted system of ion extraction, acceleration and focusing. Slits **82** in electrode **11** may be made radially, as shown in FIG. **7**, and uniformly distributed about the entire surface of disk electrode **11**. However, owing to radial slits **82**, conditions arise leading to the emergence of azimuthal velocities of part of the ions, which adversely affects the focusing of the ion beam.

It is, therefore, preferable to make electrode **11** and a system of electrodes **31** and **30** for the extraction, acceleration and focusing of charged particles in the form of three disks with a plurality of concentric circular slits **28**, as shown in FIG. **8**.

Accelerating electrode **30** is mounted a distance l_4 from electrode **11**, the distance being chosen so as to provide extraction of charged particles towards axis **3** and not to impair the dielectric strength of the system of extraction, acceleration and focusing of charged particles.

The plasma source of charged particles functions in the following manner.

First, a vacuum $P_1 = P_2 =$ in the range of $10^{-6} - 10^{-5}$ mm Hg is created in gas-discharge chamber **8** (FIG. **1**). Then a current is supplied into the windings of solenoids **1** and **2**, which sets up the cusp-geometry magnetic field.

Then emitting surface **20** of the cathode is heated to the working temperature. If the cathode is made of tantalum, the emitter is heated up to some 3,000°K. If the tantalum is coated with a lyer of lanthanum hexaboride, the emitter is heated to 1,800°K. A discharge voltage of 50 + 5,000 v from source **25** is set up between cylinder **14** of the cathode and the anode. Instruments **61, 62** and **63** (FIG. **4**) register the emission current of the electrons flowing from the cathode to anodes **11, 49** and **50**.

By shifting solenoids **1, 2** and **41** along axis **3** with the help of a displacement device **39**, the maximum passage of electron current to ring electrode **50** is achieved, thereby approximately superposing median surface **7** on the plane of symmetry of anodes **11** and **49**.

Then, through tube **19** (FIG. **1**) or holes **65** (FIG. 5*a*), gas is injected into region **27** (FIG. **1**) where pressure P_1 is increased to the range of $10^{-1} - 10^{-2}$ mm Hg.

If the source of charged particles gives off impulses, it is required to synchronize the time of entry of a gas impulse into region **27** with the instant of supply of a voltage pulse from source **25**.

The electrons collide with gas atoms in gas-discharge chamber **8** with the result that the gas ionizes and a gas discharge arises which is collimated by magnetic force lines **40** (FIG. 3*a*,*b*) of the gusp-geometry field.

The electrons emitted from cathode surface **20** (FIG. **1**) in region **27** take part in the creation of a radial discharge.

As a result of gas ionization, the discharge current will grow to about 100 times the electron emission current flowing in a radial direction close to median surface **7**.

One characteristic and advantage of a radial discharge burning close to median surface **7** of the gusp-geometry magnetic field consists in that discharge current density j_1 and the concentration of ions and electrons in the gas-discharge plasma are independent of the distance to axis **3**. Moreover, these values can even increase with the said distance according to the formula:

$$j_1 = j_2(Br_1/Br_2 \qquad \text{(II)}$$

where J_2 — density of discharge current at the surface of cylinder **14** of the cathode,

Br_1 and Br_2 = values of the radial components of the magnetic field at a given distance from axis **3** and on the surface of cylinder **14** of the cathode.

By formula (II) it is not difficult to obtain a tenfold increase of plasma density as solenoids **1** and **2** are moved away from axis **3**.

A high voltage, for instance +10 Kv or +300 Kv, from source **34** is applied to disk electrode **11** relative to electrode **30** of the system for extraction and acceleration of charged particles. In order to prevent an opposite electron beam created by ion beam **83** from destroying the source of ions, a potential −0.5 + −5 Kv with respect to the earth potential, is applied to electrode **31**.

When extracting electrons from a plasma source of charged ions, a potential −10 Kv or −300 Kv with respect to electrode **30**, must be applied to disk electrode **11**.

To obtain the maximum current of ions in a beam, median surface **7** together with the radial discharge plasma with the maximum concentration of charged particles, must be brought closer to emission slit **28**. This is achieved by shifting solenoids **1** and **2** along aixs **3** with the help of displacement device **39**.

The advantages offered by the present invention are as follows.

Firstly, a radial discharge in the magnetic field of two solenoids in opposition is conducive to a plasma with a large emitting surface, on the order of 100+1,000 cm^2, on whose boundary the concentration of charged particles reaches 10^{13} cm^{-3}.

Secondly, the boundary of the emitting plasma is fixed and controllable; it may be imparted any desired geometry depending on the condtions needed for preforming a flow of particles into a beam.

Thirdly, application of electrodes having emission slits permits avoiding the limiting values of the currents due to the electric fields in the emission cylindrical holes.

Fourthly, extraction of charged particles from plasma placed in a magnetic field, from a region where the axial component of the magnetic field is equal to zero, permits avoiding defocusing of the beam of charged particles due to the azimuthal velocity component which is usually present when charged particles are extracted in a magnetic field.

Fifthly, the plasma source of charged particles enables ion beams to be created with of magnitudes which are tens, and probably hundreds, of times higher than those of the most intense beams of charged particles available to date.

What is claimed is:

1. A plasma source of charged particles comprising: a gas-discharge chamber; two solenoids mounted on a single axis passing through said discharge chamber, electrically connected in opposition and designed to set up a magnetic field increasing along the radius; two electrodes mounted in said discharge chamber, a first one of which has the shape of a disk with at least one emission slit and positioned approximately on a median surface of said magnetic field, said electrodes designed for creating a radial discharge in said gas-discharge chamber close to the median surface of said magnetic field; a system of extraction, acceleration and focusing of the charged particles obtained in the source, said system being located on the outside of said gas-discharge chamber close to the emission slit of said electrode; and sources of supply for said solenoids, electrodes and system of extraction, acceleration and focusing of charged particles.

2. A plasma source, as of claim **1**, which has a third solenoid mounted on the extension of the axis of said second solenoid and performing the function of a focusing system.

3. A plasma source of charged particles, as of claim **1**, in which said solenoids are provided with soft-iron shields.

4. A plasma source of charged particles, as of claim **1**, which said solenoids can be displaced along their axis.

5. A plasma source of charged particles, as of claim **1**, in which said disk-shaped electrode is connected as an anode and made in the shape of a funnel having its mouth disposed toward said median surface, said second electrode being connected to be a cathode.

6. A plasma source of charged particles, as of claim **5**, which is equipped with a third electrode in the shape of a ring positioned on said median surface coaxially with said anode and connected to perform as an anticathode.

7. A plasma source of charged particles, as of claim **5**, which is equipped with an additional second anode analogous to said first one and symmetrical to it with respect to said median surface.

8. A plasma source of charged particles, as of claim **7**, which is equipped with a third anode in the shape of a ring positioned on said median surface coaxially with said disk-shaped anodes.

9. A plasma source of charged particles, as of claim **5**, in which said second electrode is connected as a directly heated cathode and is made up an external cylinder and an inner coaxial cylinder positioned coaxially with said disk-shaped anode and passing through a central hole in said anode.

10 A plasma source, as of claim **9**, in which on the outer surface of said external cylinder there is an emissive coating in a region adjoining said median surface.

11. A plasma source of charged particles, as of claim **9**, in which said external cylinder has a plurality of longitudinal slits uniformly spread along the circumference of the cylinder in a region adjoining said median surface.

12. A plasma source of charged particles, as of claim **5**, in which a second electrode of said electrodes is connected as an indirectly heated cathode and made in the shape of a ring positioned coaxially with said anode on said median surface, and made of a material having a high emissive power and providing uniform emission about the entire working area of the cathode, and equipped with a device for ring heating.

13. A plasma source of charged particles, as of claim **5**, in which said second electrode is connected as a directly heated cathode and made in the shape of a disk with a cross-section varying along its radius, providing uniform emission of electrons about the entire surface of the disk and positioned coaxially with said disk-shaped anode at a distance from said median surface providing for plasma extraction into a region immediately adjoining said median surface.

14. A plasma source of charged particles, as of claim **5**, in which said second electrode is connected as an indirectly heated cathode and made in the shape of a disk positioned coaxially with said disk-shaped anode at a distance from said median surface providing for plasma extraction into a region immediately adjoining said median surface, and equipped with a device for disk heating.

15. A plasma source of charged particles, as of claim **5**, in which said second electrode is a hollow cathode made up of two coaxial tubes connected together at one end positioned coaxially with said disk-shaped anode at a distance from said median surface providing for electron ejection from the inner tube and plasma formation in a region adjoining said median surface.

16. A plasma source of charged particles, as of claim 5, in which said second electrode is connected as a cathode and shaped like a ring positioned on said median surface coaxially with said disk-shaped anode close to said emission slit of said anode which has a circular configuration.

17. A plasma source of charged particles, as of claim 1, in which said disk-shaped electrode is a cold cathode shaped like a funnel with the mouth toward said median surface, said second electrode is connected as an anode and shaped like a rod positioned coaxially with said disk-shaped electrode, with its end pressed against said median surface, and there is a third electrode which is cold cathode, analogous to said first electrode and symmetrical to said first electrode with respect to said median surface, and a fourth electrode which is also a cold cathode in the shape of a ring positioned on said median surface coaxially with said disk-shaped electrode.

18. A plasma source of charged particles, as of claim 1, having a plurality of emission slits which are radial and spread uniformly about the entire surface of said disk-shaped electrode.

19. A plasma source of charged particles, as of claim 18, in which said system of electrodes for the extration, acceleration and focusing of charged particles is built around two disk-shaped electrodes with concentric circular slits on a side of said disk-shaped electrode external with respect to said median surface in order to create a discharge at a distance providing for the extraction and focusing of hollow beams of charged particles in the direction of the axis of said solenoids, as well as providing for the electric stability of said system of electrodes for the extraction, acceleration and focusing of particles, and wherein said circular slits of the electrodes of the system of extraction are aligned opposite said emission slits of the discharge-producing electrodes.

20. A plasma source of charged particles, as of claim 1, having a plurality of emission slits which are radial and distributed uniformly about the entire surface of said disk-shaped electrode.

21. A plasma source of charged particles, as of claim 19, in which said system of electrodes for the extraction, acceleration and focusing of charged particles is built around two disk-shaped electrodes with radial slits uniformly spread about the entire surface of the electrodes, situated on a side of said disk-shaped electrode external with respect to said median surface in order to provide a discharge at a distance providing for the extraction and focusing of charged particles in the direction of the axis of said solenoids, as well as providing for the dielectric strength of said system of electrodes for the extraction, acceleration and focusing of particles, and wherein said slits of the electrodes of the system of extraction are aligned opposite said emission slits of the discharge-producing electrodes.

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