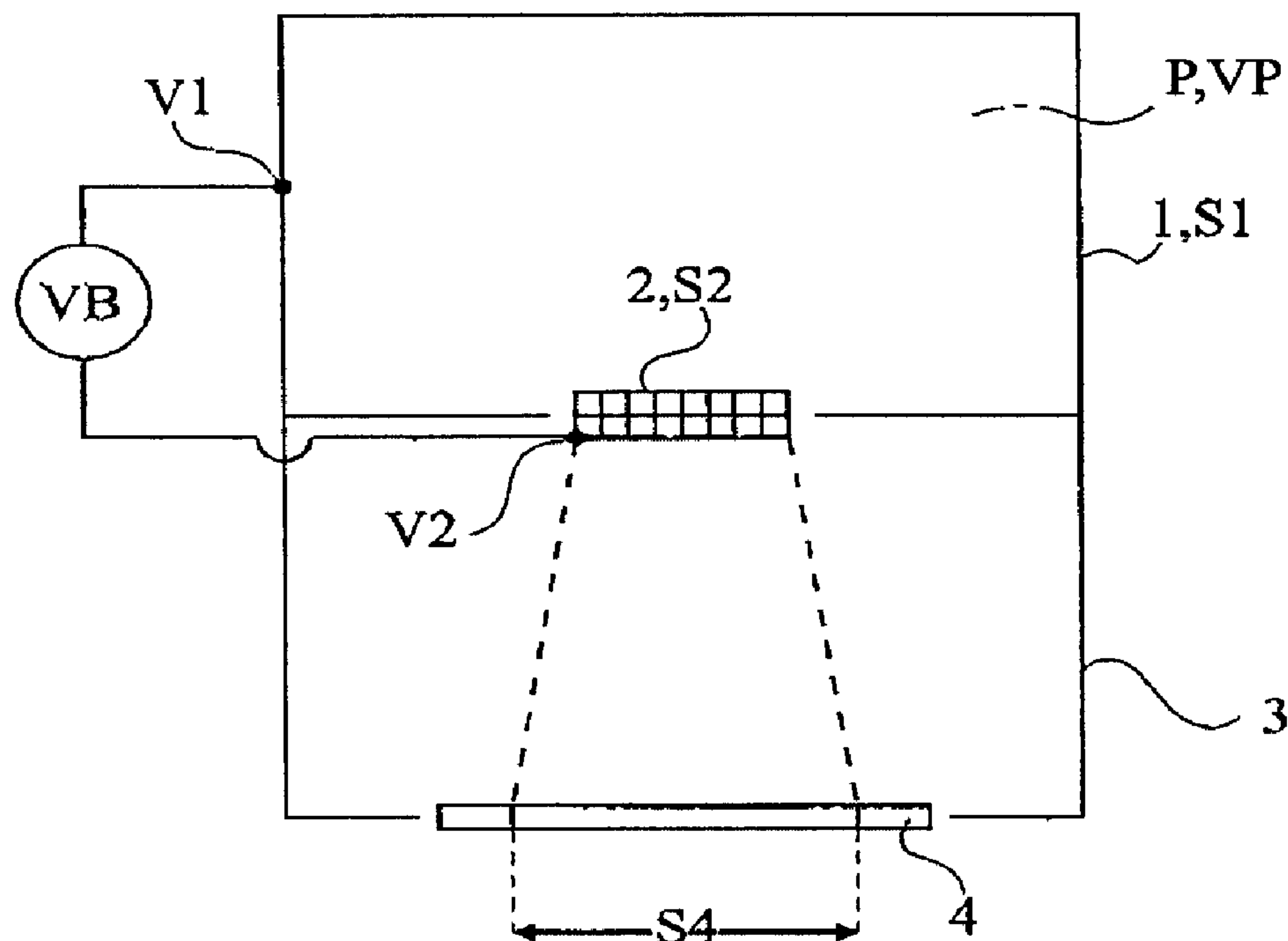




(86) Date de dépôt PCT/PCT Filing Date: 2002/12/06
(87) Date publication PCT/PCT Publication Date: 2003/06/12
(85) Entrée phase nationale/National Entry: 2004/05/28
(86) N° demande PCT/PCT Application No.: FR 2002/004223
(87) N° publication PCT/PCT Publication No.: 2003/049139
(30) Priorité/Priority: 2001/12/07 (01/15897) FR

(51) Cl.Int.⁷/Int.Cl.⁷ H01J 37/077, H01J 3/02
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(54) Titre : SOURCE D'ELECTRONS
(54) Title: ELECTRON SOURCE



(57) **Abrégé/Abstract:**

The invention concerns a source supplying an adjustable energy electron beam, comprising a plasma chamber (P) consisting of an enclosure (1) having an inner surface of a first value (S_1) and an extraction gate (2) having a surface of a second value (S_2), the gate potential being different from that of the enclosure and adjustable. The invention is characterized in that the plasma is excited and confined in multipolar or multidipolar magnetic structures, the ratio of the second value (S_2) over the first value (S_1) being close to: $D = 1/\beta \sqrt{2\pi m_e/m_i} \exp(-1/2)$, wherein: β is the proportion of electrons of the plasma P, m_e the electron mass, and m_i is the mass of positively charged ions.



(12) DEMANDE INTERNATIONALE PUBLIÉE EN VERTU DU TRAITÉ DE COOPÉRATION
EN MATIÈRE DE BREVETS (PCT)

VERSION CORRIGÉE

(19) Organisation Mondiale de la Propriété
Intellectuelle
Bureau international(43) Date de la publication internationale
12 juin 2003 (12.06.2003)

PCT

(10) Numéro de publication internationale
WO 03/049139 A1(51) Classification internationale des brevets⁷ :**H01J 37/077**, 3/02

(21) Numéro de la demande internationale :

PCT/FR02/04223

(22) Date de dépôt international :

6 décembre 2002 (06.12.2002)

(25) Langue de dépôt :

français

(26) Langue de publication :

français

(30) Données relatives à la priorité :

01/15897 7 décembre 2001 (07.12.2001) FR

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(81) États désignés (national) : CA, JP, US.

(84) États désignés (régional) : brevet européen (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SI, SK, TR).

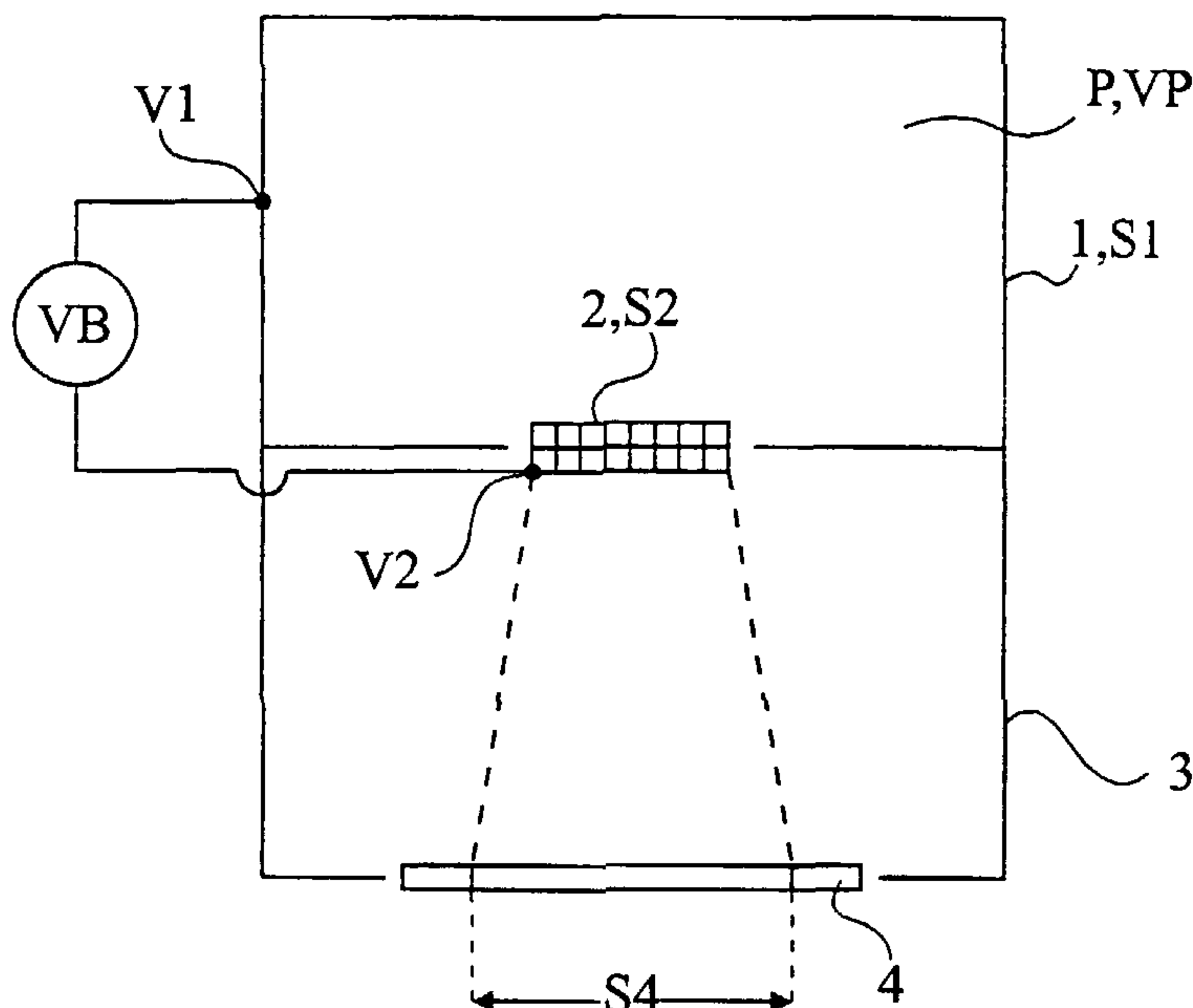
Publiée :

— avec rapport de recherche internationale

[Suite sur la page suivante]

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(57) Abrégé : L'invention concerne une source fournissant un faisceau d'électrons d'énergie réglable, comprenant une chambre à plasma (P) constituée d'une enceinte (1) ayant une surface interne d'une première valeur (S_1) et d'une grille d'extraction

(2) ayant une surface d'une seconde valeur (S_2), le potentiel de la grille étant différent de celui de l'enceinte et étant réglable, caractérisée en ce que le plasma est excité et confiné dans des structures magnétiques multipolaires ou multidipolaires, le rapport de la seconde valeur (S_2) sur la première valeur (S_1) étant proche de (formule) où : β est le taux d'électrons du plasma P, m_e la masse de l'électron, et m_i est la masse des ions chargés positivement.

WO 03/049139 A1

WO 03/049139 A1



(48) Date de publication de la présente version corrigée:
16 octobre 2003

(15) Renseignements relatifs à la correction:
voir la Gazette du PCT n° 42/2003 du 16 octobre 2003,
Section II

En ce qui concerne les codes à deux lettres et autres abréviations, se référer aux "Notes explicatives relatives aux codes et abréviations" figurant au début de chaque numéro ordinaire de la Gazette du PCT.

ELECTRON SOURCE

The present invention relates to the field of electron sources. More specifically, the present invention relates to the forming of extended electron beams intended to be injected into a plasma, under vacuum, or in any reactive gaseous atmosphere at
5 reduced pressure.

On manufacturing of circuits in semiconductor devices, certain deposition or etch steps performed in ionized gases use electron sources. Indeed, it may for example appear to be necessary to negatively bias the surface of a substrate by bombarding
10 it with an electron beam. An electron source may further be necessary to generate a plasma, to increase the ionization rate of a plasma, or yet to accelerate the ions of a plasma in which a substrate is placed. Further, different electron beam powers are desired to be used according to the considered application. For
15 example, it may be necessary to have an electron beam with a power on the order of 100 eV to enable erosion (etch) of a substrate.

Electron sources of point type such as a heated emissive cathode are already available. However, such sources have the disadvantage of providing beams with a very small cross-section.
20 The maximum possible processing surface area is thus very limited. Further, such sources can seldom be used in the considered applications, since the involved gases (plasma) risk reacting with the electrode.

Part 5.5.2 "Electron beam characteristics of miniaturized ECR plasma cathodes" of work "Electron Cyclotron Resonance Ion Sources and ECR Plasmas" by R. Geller, published by the Institute of Physics Publishing Bristol and Philadelphia (pages 352-353) describes electron sources in which electrons are
25 extracted from a plasma. However, such sources cannot be sources of large surface area. Indeed, to be able to increase the electron extraction surface area of a plasma, the plasma volume has to be increased. Then, obtaining the electromagnetic field necessary to excite the plasma at the cyclotron resonance imposes generation of
30

a continuous axial magnetic field of excessively high intensity.
35 The generation of such a magnetic field, intended to confine the trajectory of the extracted electrons around the magnetic field lines imposes using particularly complex, bulky, and expensive installations. Further, the presence of a continuous axial magnetic field may be a problem in certain applications. This
40 limits the extraction surface area to a few square millimeters. Further, electron sources of this type generate electron beams of an intensity limited to the order of one hundred milliamperes. Further, the current density exhibits an exponential-type variation along with the beam extraction power. It is thus
45 impossible to extract on an extended surface area an electron beam of a current density which remains relatively steady when the beam extraction potential is modified. Further, said potential is at most on the order of some hundred volts.

The present invention aims at providing an electron
50 source which exhibits at least some of the following features:

- usable for different application fields,
- capable of providing a beam, with as high as possible an electron current density,
- relatively steady when the beam power is varied,
- 55 - beam power controllable within a wide range,
- surface area as extended as possible, for example, with a diameter from a few centimeters to a few tens of centimeters, or more,
- free of the problems of known sources, and especially, exhibit-
- 60 ing no axial magnetic field at the level or downstream of the extraction.

To achieve these objects, the present invention provides a source providing an electron beam of settable power, comprising a plasma chamber formed of an enclosure having an internal surface
65 area of a first value and of an extraction grid having a surface area of a second value, the grid potential being different from that of the enclosure and being settable, characterized in that the plasma is excited and confined in multipolar or multidipolar

magnetic structures, the ratio of the second value to the first
 70 value being close to the following upper limit:

$$D = \frac{1}{\beta} \sqrt{\frac{2\pi m_e}{m_i}} \exp(-1/2),$$

where: β is the electron ratio of plasma P,

m_e is the mass of the electron, and

m_i is the mass of the positively-charged ions,

75 whereby the electron current density of the extracted beam is
 substantially steady when the grid-enclosure potential difference
 varies.

According to an embodiment of the present invention, the
 plasma is excited and confined by microwaves at the distributed
 80 electronic cyclotron resonance.

According to an embodiment of the present invention, the
 ratio between the second value and the first value is selected to
 be between $D/10$ and D .

According to an embodiment of the present invention, the
 85 ratio between the second value and the first value is selected to
 be between $D/2$ and D .

According to an embodiment of the present invention, the
 grid is divided into a plurality of elementary grid portions.

According to an embodiment of the present invention,
 90 various grid portions are gathered and set to distinct potentials.

According to an embodiment of the present invention, the
 source is followed by a post-acceleration enclosure.

According to an embodiment of the present invention, the
 gate is formed of parallel tubes run through by a cooling fluid.

95 The foregoing objects, features, and advantages of the
 present invention will be discussed in detail in the following
 non-limiting description of specific embodiments in connection
 with the accompanying drawings, among which:

Fig. 1 schematically illustrates a charged particle
 100 extraction plasma chamber;

Fig. 2 illustrates the electronic and ionic currents at
 the level of a surface of a chamber according to Fig. 1; and

Fig. 3 schematically illustrates an alternative electron source according to the present invention.

105 According to the present invention, a plasma chamber using excitation and confinement structures using multipolar or multidipolar magnetic structures at the distributed electron cyclotron resonance such as described, for example, in French patent applications N°85/08836, 93/02414, 94/13499, and 99/10291,
110 is used as an electron source.

Such low-pressure plasma excitation devices advantageously enable increasing the surface area of extraction of an electron beam without imposing large magnetic field volumes, and while avoiding the presence of a magnetic field at the level and
115 downstream of the extraction.

Fig. 1 schematically and partially illustrates a specific embodiment of the present invention. A confinement chamber of a plasma P is formed of an enclosure 1 with an internal surface area S_1 and of an extraction grid 2 of surface area S_2 .
120 Grid 2, isolated from enclosure 1, is biased by a voltage V_B to potential V_2 with respect to this enclosure. Voltage V_B is settable by a used. Electrons are desired to be extracted from plasma P. Potential V_2 of grid 2 must be greater than potential V_1 of enclosure 1, that is, voltage V_B is positive ($V_B =$
125 $(V_2 - V_1) > 0$). The multipolar or multidipolar magnetic excitation structures are not shown in Fig. 1. These will be, for example, structures similar to those described in the above-mentioned French patent applications.

The electron beam thus generated penetrates through grid
130 2 into an enclosure 3 of confinement of a processing atmosphere (gas, ionized gas, or plasma) of an element to be processed 4, such as a semiconductor substrate. The beam coming from grid 2 penetrates into enclosure 3 and enables processing and/or negatively biasing a surface S_4 of substrate 4.

135 Fig. 2 illustrates the theoretical variation of the currents corresponding to the particles extracted from plasma P

according to the value of extraction voltage V_B . An electron current I_e is considered as being positive and a positive ion current I_i is considered as being negative. More specifically, it is known, for example from French patent application N°95/04729 issued to the CNRS, that the electron current I_e and the positive ion current I_i that can be extracted from plasma P depend on difference $U = V_B - V_p$, where V_p is the potential of plasma P. When U is negative and ranges between V_f and zero, electron current I_e increases according to an exponential law to a maximum saturation value I_{esat} . When U is positive, that is, when bias potential V_B exceeds the potential of plasma V_p , the extracted electron current remains constant at maximum saturation voltage I_{esat} . However, the extracted positive ion current I_i remains substantially constant as long as U is negative. When U is positive, ion current I_i becomes zero. Fig. 2 also illustrates in dotted lines real current I_r , that is, the algebraic sum of electron and positive ion currents I_e and I_i . The value of U for which electron current I_e is equal to positive ion current I_i , that is, for which real current I_r is zero, is called the floating potential V_f .

A priori, to obtain a source such as defined hereabove, it should be enough to apply a voltage V_B sufficiently high to be in the saturation field, to the right of the curve of Fig. 2. In practice, account must be taken of an adjustment with respect to one another of potential V_p of plasma P and of potentials V_1 of enclosure 1 and V_2 of grid 2. Indeed, such a self-adjustment enables guaranteeing at any time the neutrality of plasma P. To keep the neutrality principle, the positive ion current on all electrode surfaces must at any time exactly compensate for the electron current on these surfaces.

To reach saturation I_{esat} on grid 2, the characteristic of Fig. 2 shows that the adjustment must be performed so that

potential V_2 of grid 2 is greater than potential V_p . Similarly, to
 170 respect the neutrality principle, that is, so that surface area S_1
 of enclosure 1 can absorb the ion current compensating for this
 saturation current I_{esat} , potential V_1 of enclosure 1 must be
 smaller than potential V_f . Surface area S_1 then receives both an
 ionic saturation current and an electronic current, as illustrated
 175 in Fig. 2.

In steady state, the saturation electronic current
 towards grid 2 is given by the following relation:

$$I_2 = I_{\text{esat}} = -e \beta n S_2 \sqrt{\frac{k_B T_e}{2\pi m_e}},$$

where: $-e$ is the electronic charge,

180 β is the electron ratio of plasma P,

n the ion density of plasma P,

S_2 the surface area of grid 2,

k_B is Boltzmann's constant,

T_e is the electron temperature in the beam, and

185 m_e is the mass of the electron.

The current collected by enclosure 1 is the sum of a
 positive ionic saturation current and of an electronic current and
 can be expressed as follows:

$$I_1 = enS_1 \sqrt{\frac{k_B T_e}{m_i}} \exp(-1/2) - e\beta nS_1 \sqrt{\frac{k_B T_e}{2\pi m_e}} \exp\left[\frac{e(V_1 - V_p)}{k_B T_e}\right],$$

190 where m_i is the mass of the positively-charged ions.

Then, to respect to plasma neutrality condition, there
 must be $I_1 + I_2 = 0$, which results in the following relation:

$$V_p - V_1 = -\frac{k_B T_e}{e} \ln\left[\frac{1}{\beta} \sqrt{\frac{2\pi m_e}{m_i}} \exp(-1/2) - \frac{S_2}{S_1}\right].$$

Further, the automatic adjustment of the potentials must
 195 be performed so that this difference is positive. The surface area
 ratio must thus be such that:

$$\frac{S_2}{S_1} < \frac{1}{\beta} \sqrt{\frac{2\pi m_e}{m_i}} \exp(-1/2).$$

To simplify the rest of the discussion, the optimal limit thus defined will be called D, that is:

$$D = \frac{1}{\beta} \sqrt{\frac{2\pi m_e}{m_i}} \exp(-1/2) \cong \frac{1.5}{\beta} \sqrt{\frac{m_e}{m_i}}$$

This condition being fulfilled, surface area S_1 takes a potential V_1 close to floating potential V_f , potential V_2 of surface area S_2 takes a positive value with respect to plasma potential V_p and receives an electronic current density equal to the electronic saturation current density. The power of the electrons in the beam output by grid 2 then is on the order of extraction power eV_B , assuming that the thermal power of the electrons $k_B T_e$ is negligible as compared to V_B . The beam power thus only depends on the potential difference V_B applied by the user between grid 2 and enclosure 1.

If the upper limit thus defined is exceeded, the obtained source exhibits an extended surface area, but the density of the electronic current of the extracted beam is no longer substantially steady with respect to the extraction power and varies exponentially with the extraction power.

According to the present invention, it is however possible to obtain a beam with an extended cross-section of substantially constant intensity (I_{esat}) and of controlled variable power (eV_B). More specifically, it is possible to vary at the output of the extraction chamber the electron power within a range from a few eV to a few hundreds of eV, instead of some ten eV with prior devices. This result is obtained without modifying the level of the extracted electronic current. Said current depends on the plasma density and may reach current densities of from a few tens to a few hundreds of mA/cm².

According to the present invention, the current is substantially steady, that is, its variation according to extrac-

tion voltage U does not have an exponential character (of type e^U), but is of type U^α , with $\alpha < 1/2$, for example according to a
230 $\sqrt{U}$ law.

According to the present invention, it is also possible to optimize extraction surface area S_2 . Surface area S_2 is chosen so that ratio S_2/S_1 of the extraction surface area to the internal surface area of enclosure 1 of the chamber is smaller than limit
235 D , but as close as possible thereto.

To increase the surface area S_4 that can be processed, the grid may be split as illustrated in Fig. 3, the sum of surface areas S_{21} , S_{22} , ..., S_{2n} of the grid portions corresponding to above-mentioned surface area S_2 . Indeed, by a beam dispersion
240 effect, the processed surface area is greater than the extraction surface area. The openings are formed close to one another so that the beams partially cover one another at the level of element 4 as they scatter, so that surface area S_4 is continuously bombarded. All the grid portions can be biased to a same voltage V_B . It may
245 also be chosen to gather the grid portions into assemblies biased to distinct voltages.

Another advantage of this splitting of extraction surface area S_2 is to guarantee a better cooling down thereof. Indeed, if an electron current with a relatively high density
250 I_{esat} is desired to be extracted, a relatively high thermal power generation can be observed at the grid level. Now, it is easier to cool down a plurality of elementary grids than a continuous extraction grid, especially because the surface separating two elementary grids can be used as a radiator or cooled down by the
255 flowing of a fluid. It is thus possible according to the present invention to ensure an efficient cooling down even for relatively high extraction powers while guaranteeing an extended extraction surface area. For the extraction from plasmas of very high densities, a direct cooling down of the grid will have to be provided,
260 by forming it by means of a bundle of parallel tubes of a diameter

on the order of one mm spaced apart by a distance on the order of one mm.

As a non-limiting example, if the plasma is an argon plasma having atomic number 40, $\beta = 1$ and ratio S_2/S_1 must be smaller than $D = 1.5/(1836.40)^{1/2}$, that is, $1/180$. In a practical example, the good operation of the system in the specific case where the extraction grid had a 4-cm diameter and where the plasma chamber was a cylinder with a 20-cm height and a 25-cm diameter has been confirmed. In this case, $S_2 = 12.5 \text{ cm}^2$ and $S_1 = 2550 \text{ cm}^2$, ratio S_2/S_1 thus is $1/204$, which fulfills the required condition. The electron current that could be extracted from the plasma was practically 0.5 ampere under an extraction voltage V_2-V_1 of 60 V.

Of course, the present invention is likely to have various alterations, modifications, and improvements which will readily occur to those skilled in the art. In particular, the plasma may be formed from gases other than argon, for example, lighter gases such as hydrogen or helium.

Further, it will be within the abilities of those skilled in the art to complete the electron source illustrated in Fig. 1 with the appropriate devices necessary to its operation, described for example in French patent application N°99/10291. Similarly, processing enclosure 3 may be completed in any appropriate fashion. A post-acceleration grid or electrode may for example be provided between extraction grid 2 of the electron source and processing enclosure 3.

CLAIMS

1. A source providing an electron beam of settable power, comprising a plasma chamber (P) formed of an enclosure (1) having an internal surface area of a first value (S_1) and of an extraction grid (2) having a surface area of a second value (S_2), the grid potential being different from that of the enclosure and being settable, characterized in that the plasma is excited and confined in multipolar or multidipolar magnetic structures, the ratio of the second value (S_2) to the first value (S_1) being close to the following upper limit:

$$D = \frac{1}{\beta} \sqrt{\frac{2\pi m_e}{m_i}} \exp(-1/2),$$

where: β is the electron ratio of plasma P,

m_e is the mass of the electron, and

m_i is the mass of the positively-charged ions,

whereby the electron current density of the extracted beam is substantially steady when the grid-enclosure potential difference varies.

2. The source of claim 1, characterized in that the plasma is excited and confined by microwaves at the distributed electron cyclotron resonance.

3. The source of claim 1, characterized in that the ratio between the second value (S_2) and the first value (S_1) is selected to be between $D/10$ and D .

4. The source of claim 1, characterized in that the ratio between the second value (S_2) and the first value (S_1) is selected to be between $D/2$ and D .

5. The source of claim 1, characterized in that the grid is divided into a plurality of elementary grid portions (S_{21} , S_{22} , ... S_{2n}).

6. The source of claim 5, characterized in that various grid portions are gathered and set to distinct potentials.

7. The source of claim 1, characterized in that it
5 is followed by a post-acceleration enclosure.

8. The source of claim 1 or 5, characterized in that the gate is formed of parallel tubes run through by a cooling fluid.

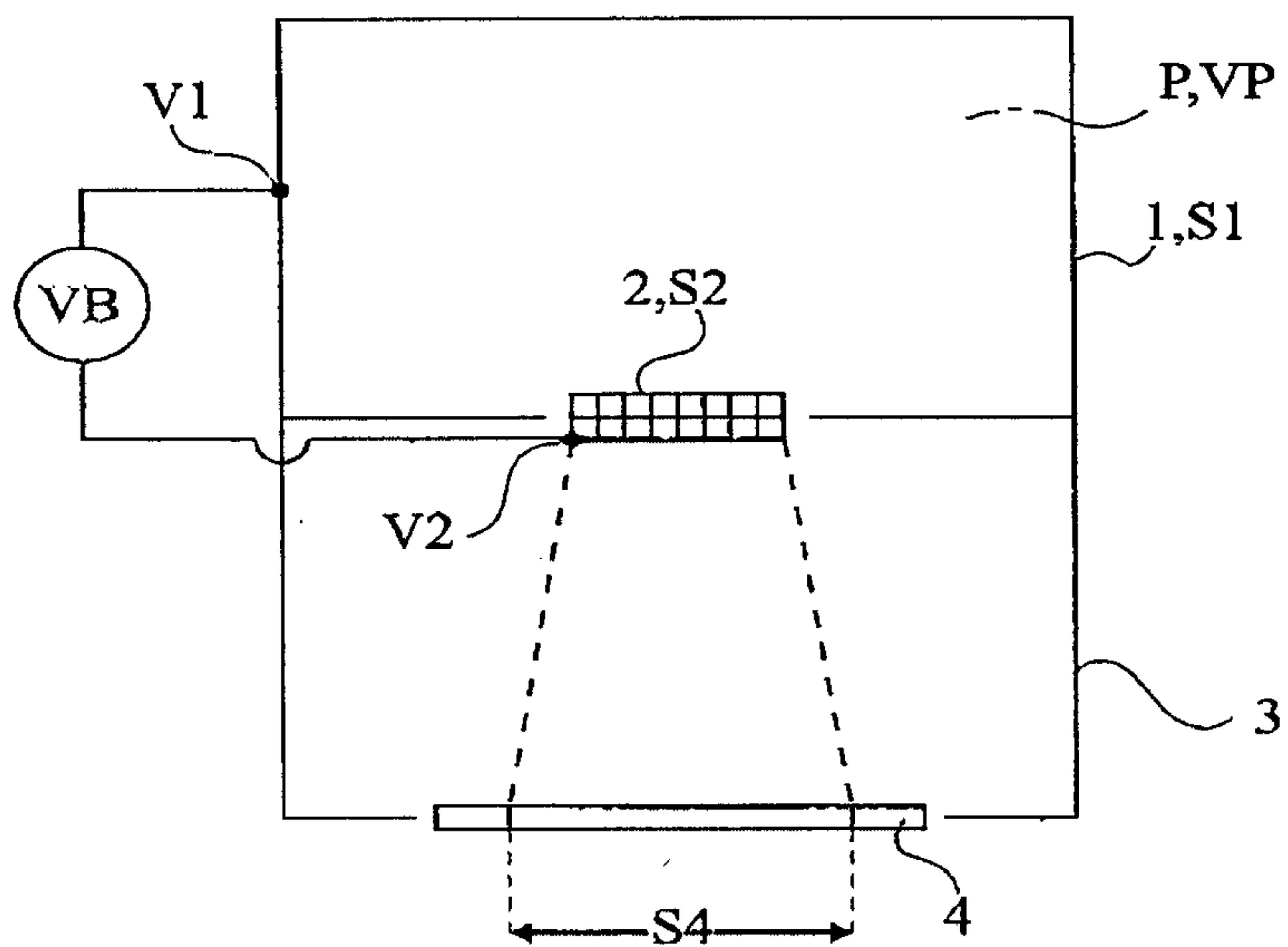
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Fig 1

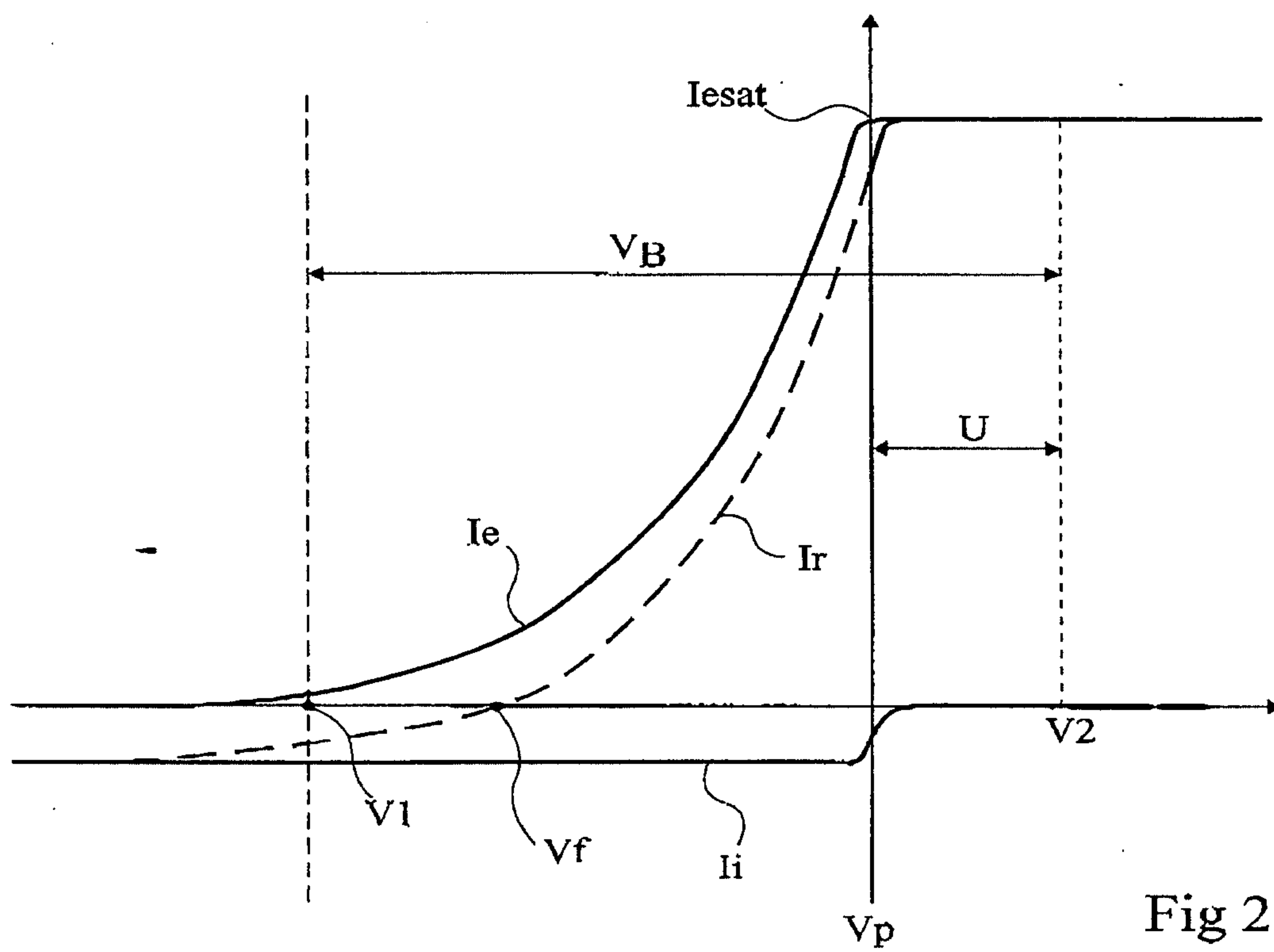


Fig 2

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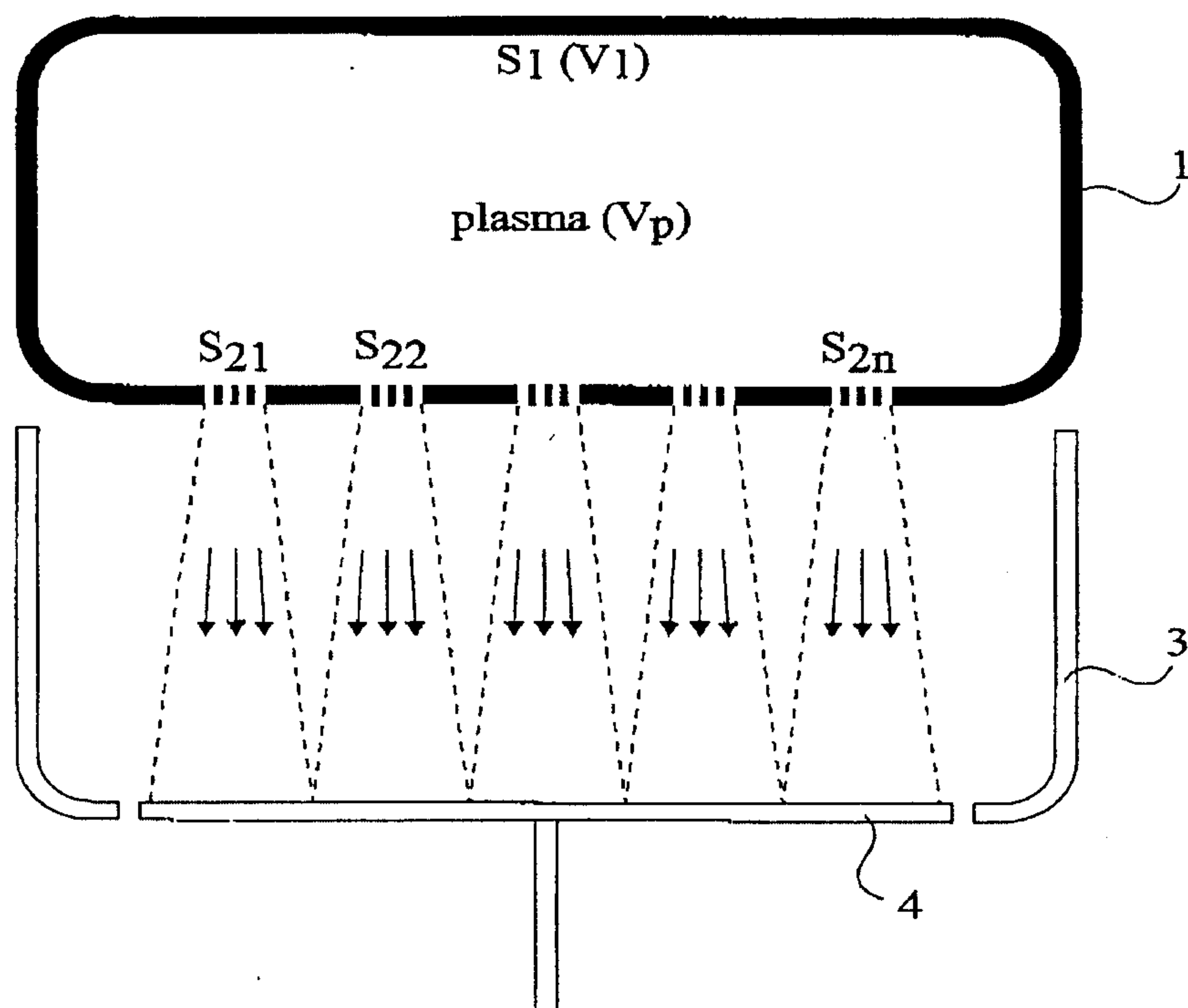


Fig 3

