Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2023410 C 2002/02/19

(11)(21) 2 023 410

(12) BREVET CANADIEN
CANADIAN PATENT
(13) C

(22) Date de dépôt/Filing Date: 1990/08/16
(41) Mise à la disp. pub./Open to Public Insp.: 1991/02/18
(45) Date de délivrance/Issue Date: 2002/02/19
(30) Priorité/Priority: 1989/08/17 (P 39 27 089.0) DE

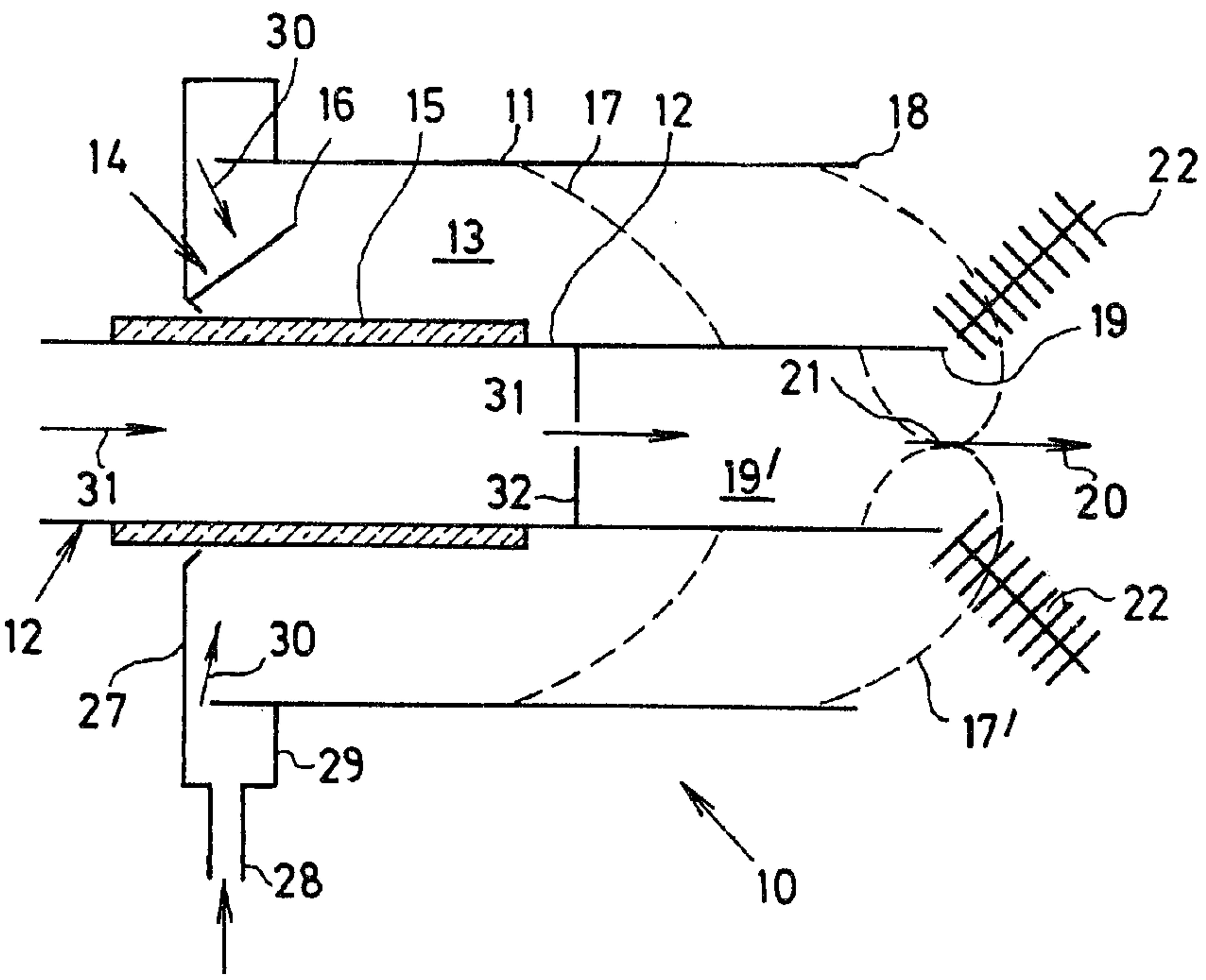
(51) Cl.Int.^{5}/Int.Cl.^{5} H01J 35/20

(72) Inventeurs/Inventors:
Richter, Franz, DE;
Lebert, Rainer, DE;
Holz, Raymond, DE;
Neff, Willi, BE

(73) Propriétaire/Owner:
Carl-Zeiss-Stiftung, a Foundation established under the laws of Germany trading as Carl Zeiss, DE

(74) Agent: ROBIC

(54) Titre : GENERATEUR RADIOLOGIQUE AVEC SOURCE PLASMA
(54) Title: DEVICE FOR GENERATING X-RADIATION WITH A PLASMA SOURCE



(57) Abrégé/Abstract:
A device (10) for generating X-radiation (20) with a plasma source having two concentric cylindrical electrodes (11, 12), which can be connected to a high-voltage electrical energy source with a controlled high-power switch and which exhibit between them a discharge space (13) filled with low-pressure gas by means of evacuation, at one closed end (14) of which discharge space an insulator (15) is arranged between said electrodes (11, 12) and there is an initiating means (16) for a plasma discharge, whose plasma (17) can be accelerated to the other end (18) and, in the region of the open end (19) of the cylindrical inner electrode (12), can be compressed into a plasma focus (21) emitting X-radiation (21). In order to optimize the generation of X-radiation, a procedure is followed such that the gas between the electrodes (11, 12) is a gas (discharge gas) optimal for initiation of the plasma discharge and/or for plasma acceleration, that a gas (emitting gas) optimal for the X-radiation (20) to be generated is present at least in the region of the open end (19) of the inner electrode (12), and that the two gases (emitting gas and discharge gas) can be evacuated so as to assure a discharge space (13) with the least possible intermixing.

Abstract

A device (10) for generating X-radiation (20) with a plasma source having two concentric cylindrical electrodes (11, 12), which can be connected to a high-voltage electrical energy source with a controlled high-power switch and which exhibit between them a discharge space (13) filled with low-pressure gas by means of evacuation, at one closed end (14) of which discharge space an insulator (15) is arranged between said electrodes (11, 12) and there is an initiating means (16) for a plasma discharge, whose plasma (17) can be accelerated to the other end (18) and, in the region of the open end (19) of the cylindrical inner electrode (12), can be compressed into a plasma focus (21) emitting X-radiation (21).

In order to optimize the generation of X-radiation, a procedure is followed such that the gas between the electrodes (11, 12) is a gas (discharge gas) optimal for initiation of the plasma discharge and/or for plasma acceleration, that a gas (emitting gas) optimal for the X-radiation (20) to be generated is present at least in the region of the open end (19) of the inner electrode (12), and

that the two gases (emitting gas and discharge gas) can be evacuated so as to assure a discharge space (13) with the least possible intermixing.

(Fig. 1)

This invention relates to a device for generating X-radiation with a plasma source having two concentric cylindrical electrodes, which can be connected to a high-voltage electrical energy source with a controlled high-power switch and which exhibit between them a discharge space filled with low-pressure gas by means of evacuation, at one closed end of which discharge space an insulator is arranged between said electrodes and there is an initiating means for a plasma discharge, whose plasma can be accelerated to the other end and, in the region of the open end of the cylindrical inner electrode, can be compressed into a plasma focus emitting X-radiation.

A device of this type is known from DE-OS [German (Fed. Rep.) Unexamined Application] 33 32 711. This so-called plasma focus device is operated with a gas charge or with a certain steady through-flow of gas. Only a single gas is used, so that both the discharge and the generation of the desired X-radiation takes place in one and the same gas.

It has been found that the known device exhibits a number of disadvantages. For example, the generated X-radiation varies in spectral properties depending on the gas species employed. It is thus possible that the yield of X-radiation of a certain desired wavelength is very low, or that the generation of the plasma leaves something to be desired.

It is therefore the object of the invention to improve a device of the type cited at the outset in such a fashion that it has the optimal conditions for initiation of the discharge and for acceleration of the plasma toward the open end of the cylindrical inner electrode, but simultaneously optimal conditions exist for the appearance of the desired X-radiation.

This object is achieved by virtue of the fact that the gas between the electrodes is a gas (discharge gas) optimal for initiation of the plasma discharge and/or for plasma acceleration, that a gas (emitting gas) optimal for the X-radiation to be generated is present at least in the region of the open end of the inner electrode, and that the two gases (emitting gas and discharge gas) can be evacuated so as to assure a discharge space with the least possible intermixing.

According to the present invention, there is provided a device (10) for generating X-radiation (20) with a plasma source having two concentric cylindrical electrodes (11, 12), which can be connected to a high-voltage electrical energy source with a controlled high-power switch and which exhibit between them a discharge space (13) filled with low-pressure gas by means of evacuation, at one closed end (14) of which discharge space an insulator (15) is arranged between said electrodes (11, 12) and there is an initiating means (16) for a plasma discharge, whose plasma (17) can be accelerated to the other end (18) and, in the region of the open end (19) of the cylindrical inner electrode (12), can be compressed into a plasma focus (21) emitting X-radiation **(20),** characterized by the fact that the gas between the electrodes (11, 12) is a **discharge gas optimal for** initiation of the plasma discharge **or** for plasma acceleration, that **an** emitting gas optimal for the X-radiation (20) to be generated is present at least in the region of the open end (19) of the inner electrode (12), and that the two gases (emitting gas and discharge gas) can be evacuated so as to assure **the discharge space (13) with the least possible intermixing.**

In accordance with the invention, distinct gases are employed in distinct regions of the device. The gases there are especially suitable for the respective processes. The discharge gas is optimized with respect to a parameter range, such as gas pressure, voltage and electric field strength, that is important for initiation of the plasma discharge and/or for plasma acceleration. For example, helium or another noble gas could be cited as discharge gas. For such a discharge gas, the acceleration of the plasma, that is, the shock wave, up to the open electrode end can also be optimized, specifically by means of adaptation of the length and the diameter of the inner electrode.

Furthermore, it is important for the invention that a gas-wise decoupling of the phase of generation of X-radiation from the discharge/acceleration phase is achieved, specifically by means of the emitting gas. The emitting gas can be selected such that the X-radiation produced represents an optimal radiation yield, in particular in the desired wavelength range. This wavelength range is, for example, approximately 0.5 to 5 nm for X-ray microscopy or for X-ray lithography. Cited as discharge gas, for example, is nitrogen, which is advantageous for the 2.5 nm range.

Moreover, it is further important that the two gases can be evacuated in such a fashion that the discharge space contains as little as possible of the emitting gas, which would not be optimal for initiation of the plasma discharge and/or for plasma acceleration.

In order, on the one hand, to achieve regions of little intermixing in the spaces to be charged with distinct gas for initiation of the plasma discharge and/or for plasma acceleration and, on the other hand, for the generation of X-radiation, the device is designed in such a fashion that the discharge-optimal gas (discharge gas) is injectable into the discharge space at the closed end of said discharge space and the emission-optimal gas (emitting gas) is injectable into the interior of the inner electrode, in each case toward the open end of the inner electrode.

The two gases are advantageously injected with steady flows, which have as a consequence an intermixing zone located substantially in front of and outside the diameter of the inner tube. This arrangement of the intermixing zone does not impair the principal functions in the discharge space or in the region in front of the open end of the inner tube; instead, said functions can take place without interference from the other gas in each case.

It is, however, also possible instead that the discharge gas fills the discharge space and/or the emitting gas fills the region of the open end of the inner tube for a plasma discharge with volumes injected pulsewise. Thus, while steady flows of the gases are employed in the first case, in the second case there is a kind of pulse filling, which takes place in such a fashion that, at the time of a plasma discharge and thus also during the phase of generation of X-radiation, discharge gas is present in the discharge space and emitting gas is present in the region of the open end of the inner tube. Intermixing therefore cannot occur until after the desired X-radiation has first been generated.

Gas extraction takes place in such a fashion that the discharge space contains, insofar as possible, only discharge gas, which is advantageously achieved by virtue of the fact that the outer electrode exhibits extraction points distributed around the circumference at the level of the open end of the inner electrode. As a consequence, the concentration of the emitting gas in the discharge space between the inner and outer electrodes is low. An intermixing zone comes into being, in the worst case, in the region of the extraction points in the vicinity of the open end of the inner electrode.

The device is advantageously designed in such a fashion that the inner electrode is double-walled, exhibits extraction points distributed around the circumference on the inner side of the tube in the region of its open end, and is connected to an extraction means at the other end. With this type of extraction, the region occupied by emitting gas in front of the open end of the inner tube can be kept as small as possible.

The two extraction means described above stand for the maximal and the minimal extent of the region exhibiting emitting gas. If both are used in combination, then on the one hand there is achieved by this means an influence on the extent of the region exhibiting emitting gas and also the possibility of maintaining distinct gas concentrations in this region or in the intermixing zones up to the discharge space.

It has been found that the neutral, that is, non-ionized emitting gas has a large absorption cross section for the radiation generated. Said radiation will thus serve, at least at some distance from the plasma focus or from the pinch plasma, to excite the emitting gas in undesirable fashion, and thus is no longer available for further conveyance to a work station for X-ray microscopy or X-ray lithography. It is therefore very beneficial, within the meaning of the invention, if the evacuation or extraction of the emitting gas is very efficient or takes place in a fashion that permits the further conveyance of the greatest part of the X-radiations to the processing station. In development of the invention, however, provision is made that a beam tube is arranged in front of the region of the open end of the inner electrode and coaxial therewith and is filled with a beam-tube gas optimal for the transmission of the X-radiation. Then it is achieved, at least, that no emitting gas advances into the beam tube and at least the region defined by this beam tube can be optimized for the transmission of the X-rays by means of the selection of beam-tube gas.

In development of this device, the beam-tube gas in this region of the open end of the inner tube can be allowed to flow in and can be extracted via the extraction point of the device. The inflow of the beam-tube gas can be managed in such a fashion that the region of the open end of the inner tube, which region exhibits emitting gas, is limited in its axial extent, so that the losses of X-radiation by means of absorption by non-ionized emitting gas are further reduced.

The invention is explained on the basis of exemplary embodiments illustrated in the drawing.

Fig. 1 shows a schematic cross section through a device in accordance with the invention, and

Fig. 2 shows a device similar to Fig. 1 with exemplary extraction means illustrated schematically.

The device 10 illustrated in Fig. 1 has two concentric cylindrical electrodes 11, 12, which can be connected to a high-voltage electrical energy source with a controllable high-power switch. As an example for the design of such a high-power switch and such a high-voltage energy source, reference is made to German Unexamined Application 33 32 711, in particular Fig. 1. Thus it is possible to raise the inner electrode 12 briefly to a voltage potential of several tens of kilovolts relative to the outer electrode 11, which is, for example, at ground potential. The ionization processes taking place in the discharge space between the electrodes 11, 12 as a consequence thereof are described later on.

The left end 14 of the discharge space 13 in Fig. 1 is closed with a wall 27. The wall 27 is annular, and between it and the inner electrode 12 there is an insulator 15 in the form of a cylinder tightly enclosing the inner electrode 12. The insulator 15 shields the wall 27 of the discharge space 13 from the inner electrode 12 in the sense of voltage.

The wall 27 is electrically conductively connected to the outer electrode 11 and thus has its potential. Furthermore, the inner circumference of the wall 27 forms, by means of a turned-over edge, an initiating means 16 for a plasma discharge. As a consequence of this initiating means, a plasma will develop as a result of ionization of the gas contained in the discharge space 13, which plasma develops to the right because of the terminating wall 14 in Fig. 1, and is thus strongly accelerated to the open end of the discharge space 13, so that a plasma shock wave arises. The plasma 17 or the wavefront is illustrated in Fig. 1 by way of example. When the plasma 17, as shown at 17', reaches into the region of the open end 18 of the discharge space 13 and thus into the region of the open end 19 of the inner tube 12, it is constricted by strong magnetic forces. A plasma focus 21 or pinch arises, in which focus or pinch ionized gas is compressed in such a fashion that, along with other radiation, chiefly also X-radiation 20 is emitted. This X-radiation is further conveyed to a processing station.

The discharge space 13 is filled with a gas, which flows, by means of a gas supply line 28 and an annular duct 29, into the closed end 14 of the discharge space 13 as indicated by the arrows 30. From this injection point, it flows toward the open end 18 of the outer electrode 11. With regard to its composition and its pressure in the discharge space 13, the discharge gas is selected for optimal initiation of the plasma or for plasma acceleration. The discharge gas can be evacuated from the open end 18 of the discharge space 13, so that an underpressure prevails in the discharge space 13.

In the interior 19' of the inner electrode 19, emitting gas is injected as indicated by the arrows 31. A diaphragm 32 serves to limit the quantity or restrict the entry of discharge gas, for example when filling with emitting gas takes place only in pulsed fashion.

The emitting gas advances into a region located substantially to the right of the open end 19 of the inner tube 12 in Fig. 1 and forms intermixing zones 22 with the discharge gas of the discharge space 13. It is understood that the position of these intermixing zones 22 varies depending on the pressure and the flow conditions of the two gases. In Fig. 1, the intermixing zones 22 are arranged in such a fashion that they lie substantially in front of and outside the diameter of the inner tube. As a consequence, the discharge space 13 is largely free of emitting gas, as also the region in front of the open end 19 of the inner tube 12 is largely free of discharge gas. The plasma 17 can thus be initiated and accelerated in the discharge space 13 practically without hindrance from the emitting gas, and the compressed plasma of the plasma focus 21 is formed practically exclusively from emitting gas, so that the above-described advantageous conditions prevail with respect to the generation and transport of the plasma on the one hand, and to the generation of the desired X-radiation on the other hand.

In Fig. 1, the extraction of the two gases and thus the evacuation of the plasma-filled regions is left open. Fig. 2 shows these points made concrete.

Extraction from the discharge space 13 is served by extraction points 23 present at the end 18 of said space, which extraction points are distributed around the circumference of the outer electrode 11. Thus gas flows, as indicated by the arrows 32, through the extraction points 23 into an annular duct 33, and from there through an extraction port 34 as indicated by arrow 35 to an extraction means, which was not illustrated.

Further, it can be seen from Fig. 2 that the inner electrode 12 is double-walled and has extraction points 24 at its open end 19, which extraction points are likewise distributed around the inner circumference of the inner electrode 12. At the other end of the inner electrode 12 there is an annular duct 36 with an extraction port 37, which is connected to an extraction means, so that gas is extracted from the region of the open end of the inner tube 19 as indicated by the arrows 38.

Extraction can be accomplished in such a fashion that extraction takes place either through the extraction points 23 alone or through the extraction points 24 alone. Accordingly, the emitting gas has a maximal or a minimal extent in the region of the open end 19 of the inner electrode 12. By means of combined extraction both through the extraction points 23 and through the extraction points 24, it can be achieved that the region of the emitting gas at the open end 19 is influenced as to its extent and/or in its gas composition. The flow zones and intermixing zones arising by this means are naturally also influenced by the inflowing quantities or pressures of the discharge gas or of the emitting gas.

In Fig. 2, a beam tube 26 is arranged coaxially to the right of the electrodes 11, 12. This serves for the transmission of the generated X-radiation to a work station.

It is filled with a beam-tube gas optimal for this transmission and enables the X-radiation to pass through an aperture 39' in a diaphragm 39 closing the beam tube 26 at the end.

The beam-tube gas is optimal for the transmission of X-radiation, that is, it has in particular a low absorption coefficient, so that transmission takes place largely with no loss of energy. A candidate beam-tube gas is, for example, oxygen. It is desirable that such a transmission gas is already present as near as possible to the plasma focus 21. The beam tube 26 cannot, however, be arbitrarily attached to the open end 19 of the inner electrode 12, because, for example, space is required for the shock wave of the plasma 17. It is therefore advantageous the beam-tube gas can be allowed to flow through the diaphragm aperture 39' into the region of the open end 19 of the inner tube 12 as indicated by the arrow 40. This beam-tube gas can be extracted with the other two gases. If, for example, there is a conical sealing insulation 41 between the outer electrode 11 and the beam tube 26, extraction takes place via the extraction points 32 and/or 24.

Claims

1. A device (10) for generating X-radiation (20) with a plasma source having two concentric cylindrical electrodes (11, 12), which can be connected to a high-voltage electrical energy source with a controlled high-power switch and which exhibit between them a discharge space (13) filled with low-pressure gas by means of evacuation, at one closed end (14) of which discharge space an insulator (15) is arranged between said electrodes (11, 12) and there is an initiating means (16) for a plasma discharge, whose plasma (17) can be accelerated to the other end (18) and, in the region of the open end (19) of the cylindrical inner electrode (12), can be compressed into a plasma focus (21) emitting X-radiation **(20),** characterized by the fact that the gas between the electrodes (11, 12) is a **discharge gas optimal for** initiation of the plasma discharge **or** for plasma acceleration, that **an** emitting gas optimal for the X-radiation (20) to be generated is present at least in the region of the open end (19) of the inner electrode (12), and that the two gases (emitting gas and discharge gas) can be evacuated so as to assure **the discharge space (13) with the** least possible intermixing.

2. A device in accordance with claim 1, characterized by the fact that the discharge gas is injectable into the discharge space at the closed end of said discharge space and the emitting gas is injectable into the interior (19') of the inner electrode (12), in each case toward the open end (19) of the inner electrode (12).

3. A device in accordance with Claim 2, characterized by the fact that the two gases are injected with steady flows, which have as a consequence an intermixing zone (22) located substantially in front of and outside the diameter of the inner tube.

4. A device in accordance with Claim 2, characterized by the fact that the discharge gas fills the discharge space (13) **or the emitting gas fills the region of the open end** (19) of the inner tube for a plasma discharge with volumes injected pulsewise.

5. A device in accordance with one or a plurality of Claims 1 to 4, characterized by the fact that the outer electrode (11) exhibits extraction points (23) distributed around the circumference at the level of the open end (19) of the inner electrode (12).

6. A device in accordance with one or a plurality of Claims 1 to 5, characterized by the fact that the inner

electrode (12) is double-walled, exhibits extraction points (24) distributed around the circumference on the inner side of the tube in the region of its open end (19), and is connected to an extraction means at the other end (25).

7. A device in accordance with one or a plurality of Claims 1 to 6, characterized by the fact that a beam tube (26) is arranged in front of the region of the open end (19) of the inner electrode (12) and coaxial therewith and is filled with a beam-tube gas optimal for the transmission of the X-radiation (20).

8. A device in accordance with Claim 7, characterized by the fact that the beam-tube gas in the region of the open end (19) of the inner tube (12) can be allowed to flow in and can be extracted via the extraction points (23, 24) of the device (10).

2023410

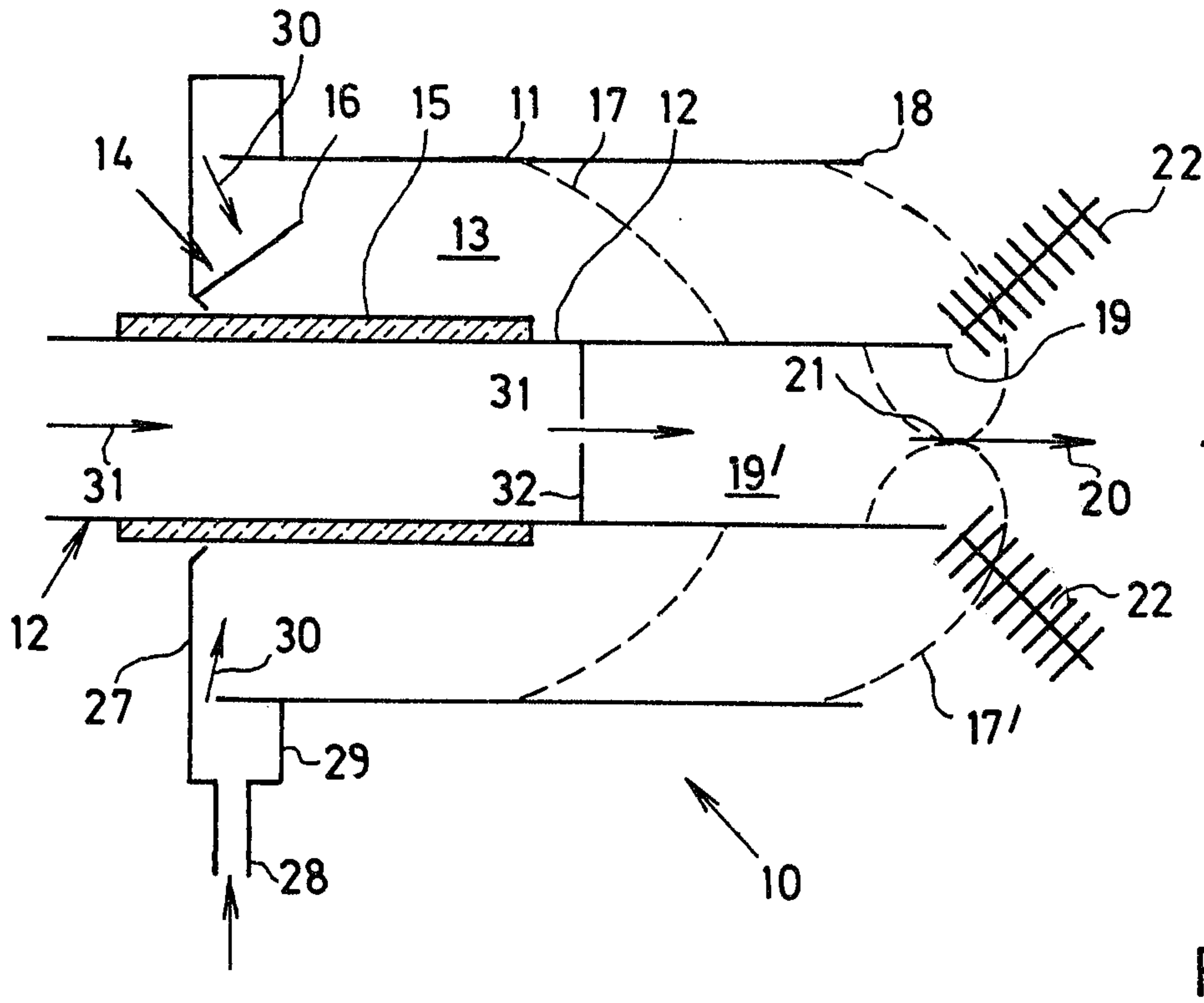


Fig.1

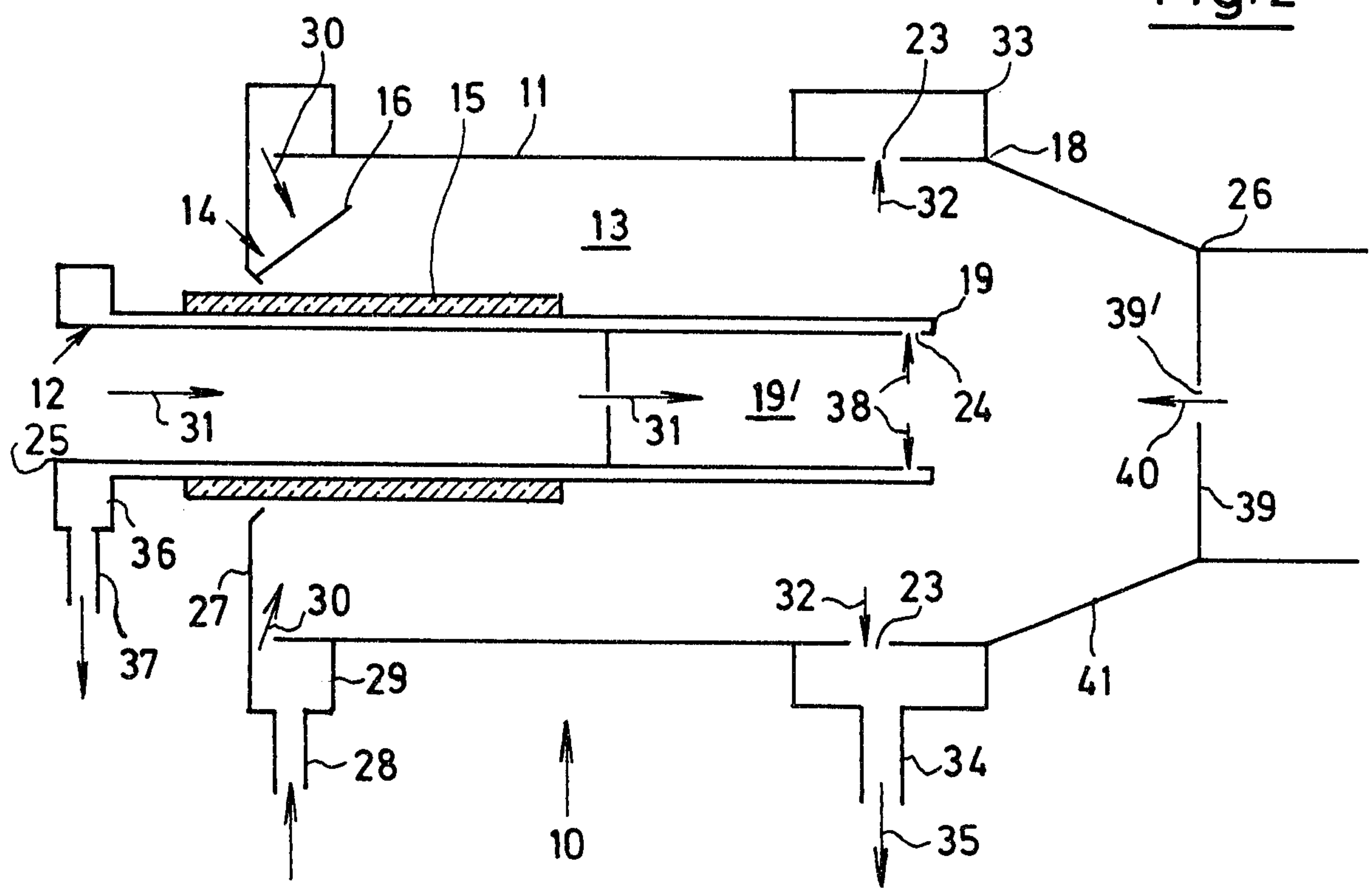
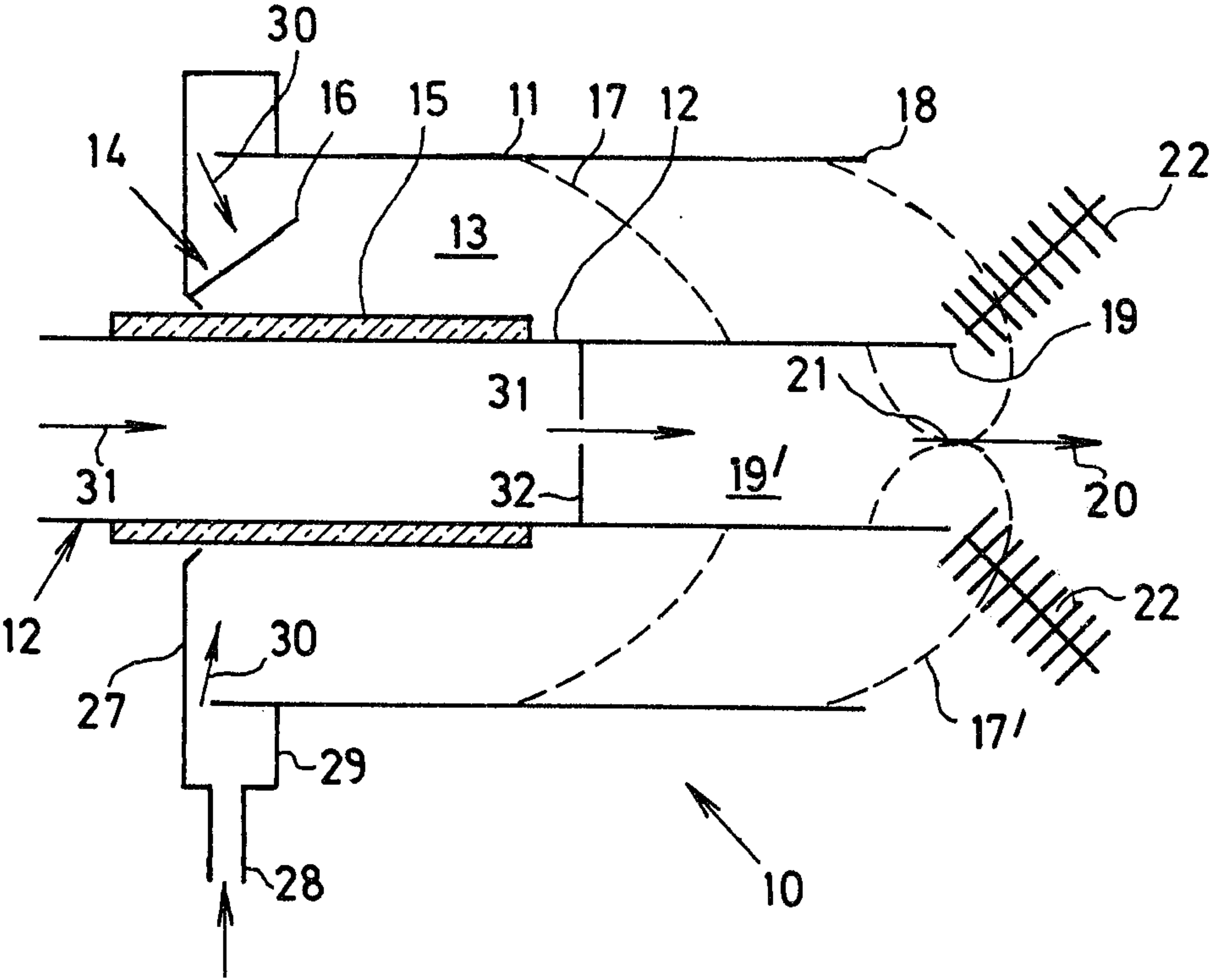


Fig.2

Patent Agents.


30
16
15
11
17
12
18
14
22
13
19
21
31
31
19'
20
32
12
22
30
27
17'
29
28
10