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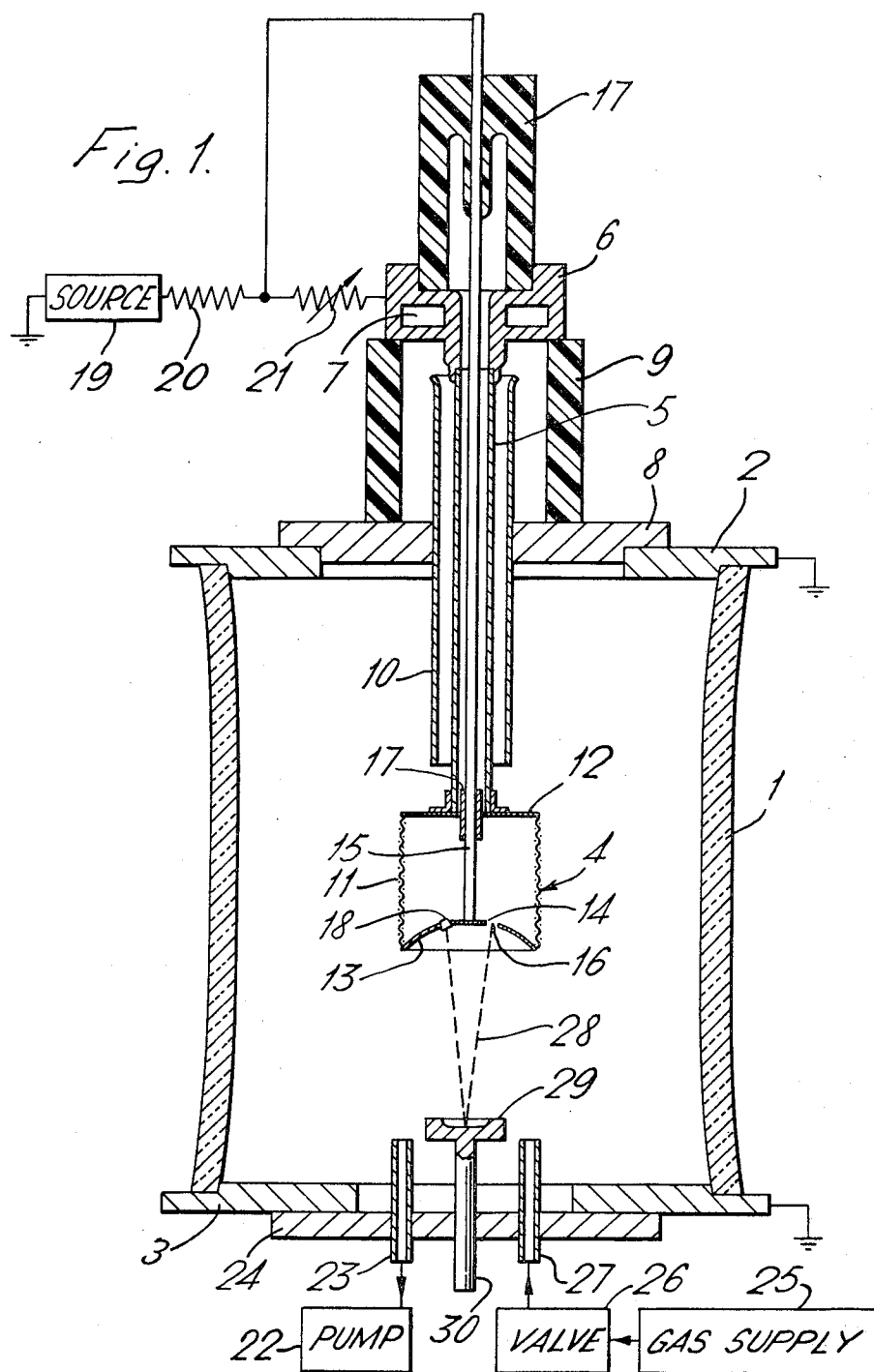
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HOLLOW CATHODE DISCHARGE DEVICE WITH CONTROL ELECTRODE
FOR ELECTRON BEAM FOCUSING

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2 Sheets-Sheet 1



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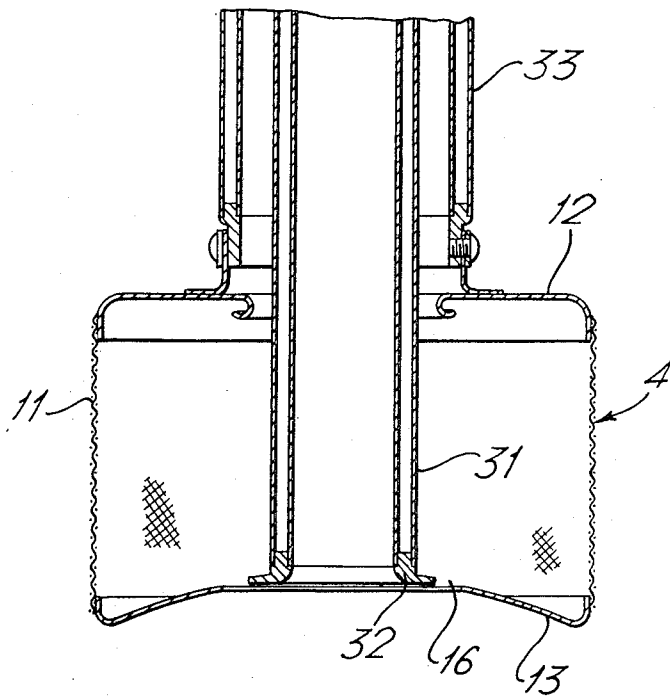
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Fig. 2.



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HOLLOW CATHODE DISCHARGE DEVICE WITH CONTROL ELECTRODE FOR ELECTRON BEAM FOCUSING

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14 Claims

ABSTRACT OF THE DISCLOSURE

A cold cathode glow discharge device includes an enclosure and means to maintain a gas in said enclosure at a predetermined pressure. A hollow cathode is formed at least partly of wire mesh, and an anode is mounted within said enclosure. The cathode includes an outwardly concave portion having an aperture therein. A further electrode is of a substantially similar outline to the shape of said aperture, said further electrode is positioned in said aperture to define a gap between a peripheral edge of said further electrode and an edge defining said aperture. Electrical potentials are applied to the anode, cathode, and further electrode such that during operation an electric discharge takes place and a stream of electrons passes through said gap to form a hollow beam which converges to a focus at a region outside said cathode.

This invention relates to cold-cathode discharge devices which form electron sources. The expression "cold-cathode" as used in this specification signifies that the cathode is non-thermionic.

More particularly, the invention relates to such devices which may, for example, be used for the heat treatment of refractory materials.

According to the present invention, a cold-cathode discharge device comprises an enclosure, means to maintain the enclosure at a low gas pressure, an anode mounted within or forming part of an interior wall of the enclosure, a hollow cathode formed at least partly of wire mesh mounted within the enclosure, one wall of the cathode being of circular outline and part spherical shape with the concave side outwards and having a central circular aperture, a further electrode of circular outline positioned in said aperture to define with said aperture an annular gap, and means to apply suitable operating potentials to the anode, cathode and further electrode.

The operating potential applied to the further electrode may be the same as, or positive relative to, or negative relative to, that applied to the cathode.

Two cold-cathode discharge devices in accordance with the present invention will now be described by way of example with reference to the accompanying drawings, in which:

FIG. 1 shows a partly diagrammatic section through the first device, and

FIG. 2 shows a similar section through a part of the second device.

Referring to FIG. 1, the first device comprises an enclosure formed by an approximately cylindrical tube 1 of heat resisting glass, about 22 cms. in diameter and 30 cms. long, closed at the ends by aluminium plates 2 and 3 with O-ring seals (not shown), and supported with its axis vertical. The plates 2 and 3 are both earthed, and in operation of the device form anodes.

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A cathode 4 is supported within the enclosure by a conducting tube 5 which extends downwards from a cathode connector 6 having a bore 7 for water cooling. The cathode connector 6 is secured to a removable portion 8 of the plate 2 by way of an insulating cylinder 9. Extending through the portion 8, concentric with the tube 5, is a conducting tube 10 which forms an earthed shield.

The cathode 4 comprises a right circular cylindrical portion 11 with a flat circular portion 12 at the top and a part spherical portion 13 at the bottom. The centre of the sphere, the surface of which the portion 13 forms a part, lies on the axis of the portion 11. The portion 13 of the cathode 4 has a central circular aperture.

A flat (or part spherical) plate of circular outline which forms a further electrode 14 is supported in the aperture in the portion 13 of the cathode 4 by a conducting rod 15, so as to leave an annular gap 16 of uniform width between the electrode 14 and the portion 13. The rod 15 passes through an insulating bush 17 in the portion 12 of the cathode 4.

For the purpose of maintaining the width of the gap 15 uniform, three symmetrically disposed, alumina pegs 18 may be pushed into the gap 16.

The portion 11 of the cathode 4 is of stainless steel or refractory wire mesh, and the portions 12 and 13, and the electrode 14 are of refractory metal plate, for example, tantalum plate. Alternatively, the portion 13 and the electrode 14 may also be formed of stainless steel or refractory wire mesh. In this case the edges of the portion 13 and the electrode 14 defining the annular gap 16 may be made smooth by welding circular rings to them.

The rod 15 is of a refractory metal, although alternatively the rod 15 may be replaced by a support formed by a cylinder of stainless steel wire mesh, this alternative being possible because of the reduced heating effect on a mesh.

Power is derived from a source 19 comprising an auto-transformer which supplies a variable voltage to the primary winding of a high voltage transformer, the output of which is rectified by a full wave rectifier. The connection to the cathode connector 6 is by way of resistors 20 and 21 in series, the resistor 21 being variable. The junction of resistors 20 and 21 is connected to the rod 15. The circuit also includes an ammeter and a voltmeter (not shown).

Evacuation of the enclosure is by means of an oil diffusion pump 22 backed by a rotary pump (not shown), connection to the pumps being by way of an outlet pipe 23 passing through a removable portion 24 of the plate 3. To measure the pressure a pirani gauge (not shown) is connected to the outlet pipe 23 immediately outside the enclosure. A gas is supplied from a gas supply cylinder 25 through a two-stage pressure regulator and a needle valve 26 to an inlet pipe 27 which also passes through the portion 24 of the plate 3. The pressure in the enclosure is controlled by adjusting the flow of gas with the pumps working continuously.

There are several ways in which the device may be operated, some of which will now be described.

In the first case the enclosure is evacuated to a pressure of approximately 5.10^{-3} torr and then filled with helium to a pressure of approximately 3.10^{-2} torr. A negative potential of approximately 2.75 kilovolts is applied to the cathode 4, the resistor 21 being set to zero, so that the same potential is applied to the electrode 14 as to the cathode 4. When outgassing of the cathode 4 has occurred, the helium pressure is allowed to rise slowly. This is done by adjustment of the valve 26.

A hollow cathode discharge develops, accompanied

by a stream of electrons which passes through the annular gap 16. Due to the shape of the portion 13 of the cathode 4, the stream of electrons tends to form a conical beam 28 which focusses on the axis of the cathode 4 approximately at the centre of the sphere of which the portion 13 forms a part. The degree of focus is dependent upon the helium pressure. With the cathode 4 at 2.75 kilovolts, the beam 28 is focussed at about 15×10^{-2} torr, but if the power of the beam 28 is increased by making the potential of the cathode 4 more negative, the beam 28 is focussed at a lower helium pressure. With the cathode 4 at 4.0 kilovolts the beam 28 is focussed at about 8×10^{-2} torr.

To use the device, the specimen which it is desired to heat is arranged within the enclosure in a crucible 29 mounted on an axially movable rod 30 which passes through portion 24 of the plate 3. The specimen is thus connected as an anode, and can be arranged to be at the focus of the electron beam 28. The crucible 29 may be water cooled.

In the second case the operation is generally similar except that the gas used is argon, in which case the pressure to which the enclosure is initially evacuated and the operating pressures are lower. The resistor 21 is set to a low value, so that the electrode 14 is at a negative potential relative to the cathode 4. A focussed beam 28 is obtained with the cathode 4 at a negative potential of 6 kilovolts and an argon pressure of 10^{-2} torr. The focus of the beam 28 can be varied by varying the value of the resistor 21.

In the third case the enclosure is evacuated and filled with helium as in the first case. With a helium pressure of 18×10^{-2} torr, the resistor 21 set to zero, and a negative potential of approximately 2.75 kilovolts applied to the cathode 4 a glow discharge occurs. This is not accompanied by an electron beam and the result of the discharge is that the potential difference between the anode (crucible 29) and the cathode 4 falls to approximately 300 volts.

On raising the value of the resistor 21 to approximately 1800 ohms the glow discharge is restricted. This manner of operation thus demonstrates that varying the potential of the electrode 14 relative to the cathode 4 can be used not only to vary the focus of an electron beam, but also to restrict and therefore control a glow discharge which would otherwise occur under certain operation conditions. This can prolong the life of the cathode 4 by reducing heating, and also makes it possible to pulse the electron beam on and off.

The device may be operated with other gases, for example, oxygen. In this case, however, it is desirable, although not essential, to make the cathode 4 of an oxidation resistant material.

The device may be used for various purposes, such as heat treatment, welding, melting or zone refinement, in which heating, particularly the heating of a refractory material, is involved.

Depending on the use to which the device is to be put, some modifications or additional features may be possible or desirable.

For example, the rod 15 may be so arranged that the electrode 14 is movable axially over a limited range. This has the effect of altering the position of the focus, or the degree of focus, of the electron beam 25.

It is also possible, and in some circumstances may be preferable, to provide a separate power supply for the electron 14, so that the electrode 14 can be maintained at a positive or a negative potential relative to the cathode 4. In either case the glow discharge can be restricted if the potential relative to the cathode 4 is made large enough, but the application of a positive potential to the electrode 14 tends to move the focus of the electron beam 28 towards the cathode 4, whereas a negative potential tends to move the focus away from the cathode 4.

An earthed screening electrode may be arranged to en-

circle the cathode 4 to reduce the loss of electrons to the walls of the enclosure.

The second device to be described is generally similar in form and operation to the first except for the configuration of the cathode and the further electrode. These parts of the second device are therefore shown diagrammatically in FIG. 2 to which reference is now made.

As before, the cathode 4 comprises a right circular cylindrical portion 11 with a flat circular portion 12 at the top and a part spherical portion 13 at the bottom. The centre of the sphere, the surface of which the portion 13 forms a part, lies on the axis of the portion 11. The portion 13 of the cathode 4 has a central circular aperture.

Extending centrally through the cathode 4 is a double-walled tube 31 having an annular portion at its lower end, this portion forming a further electrode 32 and being situated in the aperture, so as to leave an annular gap 16 of uniform width between the further electrode 32 and the portion 13.

The form and materials of the portions 11, 12 and 13 of the cathode are as in the first device, although the portions 12 and 13 are, in this case, usually of plate. The cathode 4 of the second device is bigger than that of the first device and is operable at higher powers. During operation water is pumped through the tube 31 and also through a double-walled tube 33 supporting the cathode 4.

The operation is similar to that of the first device and in particular the further electrode 32 can be operated at the same potential as the cathode 4 or at a different potential as required.

The aperture extending through the tube 31 makes it possible for a rod or the like to be fed longitudinally through the beam of electrons, for example, for zone refinement or melting. Also material may be allowed to fall through the aperture to a crucible below for crystal growing purposes. The device may also be used to evaporate material in the production of thin films. The material to be evaporated is placed in a crucible and as it evaporates it is drawn up the aperture through the tube 31, and condensed to form the film on a suitable substrate.

Provision may be made for securing a circular disc to the further electrode 32 of the second device to convert it to an arrangement similar to the first device.

I claim:

1. A cold cathode glow discharge device comprising an enclosure, means to maintain a gas in said enclosure at a predetermined pressure, an anode at least partly mounted within said enclosure, a hollow cathode formed at least partly of wire mesh mounted within said enclosure and including an outwardly concave portion having an aperture therein generally symmetrically disposed with respect to said hollow cathode, a further electrode of a substantially similar outline to the shape of said aperture, said further electrode being positioned in said aperture to define a gap between a peripheral edge of said further electrode and an edge defining said aperture, means for applying electrical potentials to said anode and cathode such that during operation an electric discharge takes place and a stream of electrons passes through said gap to form a hollow beam, and means for applying an electrical potential to said further electrode whereby said beam converges to a focus at a region outside said cathode.

2. A device in accordance with claim 1 wherein said further electrode is supported by a tube which extends centrally through the cathode, the further electrode forming one end of said tube.

3. A device in accordance with claim 2 wherein said tube is double-walled and provision is made to cool said tube with water during operation.

4. A device in accordance with claim 1 wherein said cathode is right circular cylindrical.

5. A device in accordance with claim 1 wherein the

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cathode and said further electrode are formed of stainless steel.

6. A device in accordance with claim 1 wherein the cathode and said further electrode are formed of tantalum.

7. A device in accordance with claim 1 wherein said last mentioned means comprises means for maintaining said further electrode at the same potential as the cathode.

8. A device in accordance with claim 1 wherein said further electrode is electrically insulated from the cathode, and one of said means for applying electrical potential includes means for varying the electrical potential of said further electrode relative to said cathode, and the focus of said beam of electrons is variable by selectively varying the electrical potential of said further electrode relative to said cathode.

9. A device in accordance with claim 1 wherein said further electrode is of annular shape.

10. A device in accordance with claim 1 wherein said aperture is circular and said further electrode is of a circular outline.

11. A device in accordance with claim 1 wherein said first mentioned means comprises means for maintaining a gas in said enclosure at variable pressures, and wherein said beam of electrons is further focussed by varying the pressure of the gas in the enclosure.

12. A device in accordance with claim 7 wherein said first mentioned means comprises means for maintaining

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a gas in said enclosure at variable pressures, and wherein said beam of electrons is further focussed by varying the pressure of the gas in the enclosure.

13. A device in accordance with claim 8 wherein said first mentioned means comprises means for maintaining a gas in said enclosure at variable pressures, and wherein said beam of electrons is further focussed by varying the pressure of the gas in the enclosure.

14. A device in accordance with claim 8 wherein the electric discharge is controllable by selectively varying the electrical potential of said further electrode relative to said cathode to effectively switch the electron beam on and off.

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