May 14, 1968 R. A. DUGDALE 3,383,550

COLD CATHODE, GLOW DISCHARGE DEVICES

Filed March 17, 1966 3 Sheets-Sheet 1

Fig. 1.

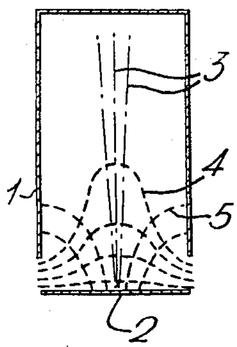


Fig. 2.

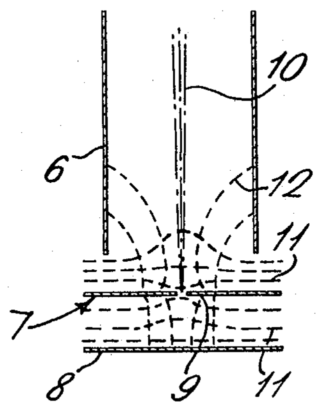


Fig. 3.

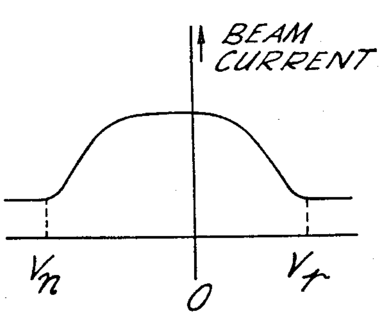


Fig. 4.

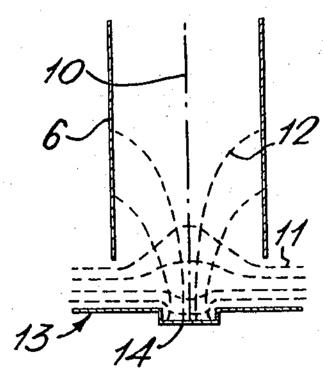


Fig. 5.

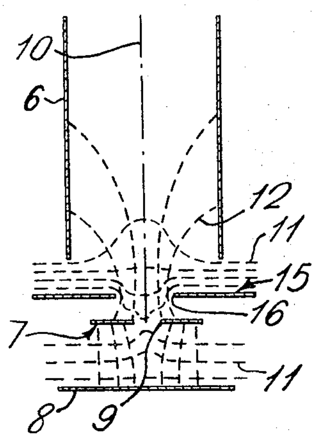


Fig. 6.

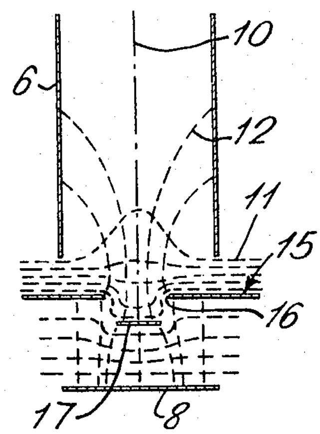


Fig. 7.

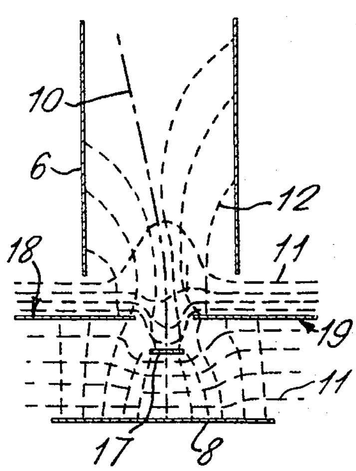
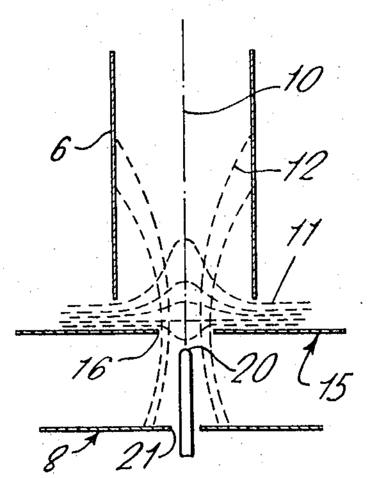


Fig. 8.



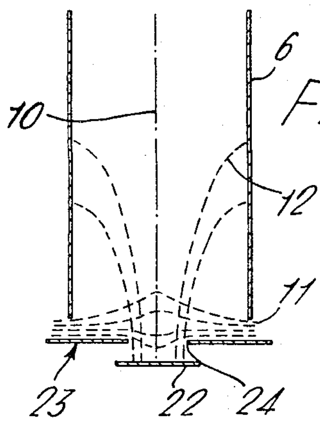


Fig. 9.

Fig. 10.

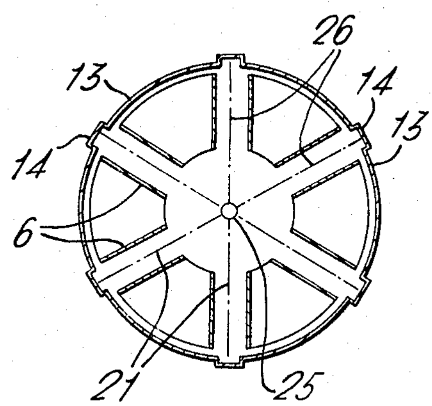
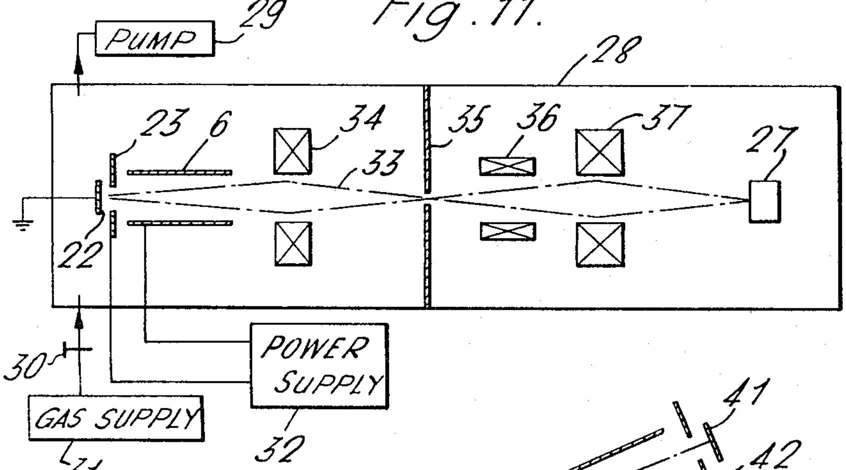


Fig. 11.



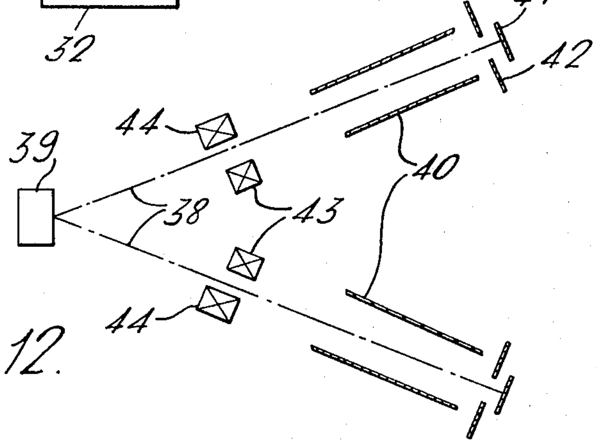


Fig. 12.

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COLD CATHODE, GLOW DISCHARGE DEVICES

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10 Claims. (Cl. 315—31)

ABSTRACT OF THE DISCLOSURE

A cold cathode glow discharge device including a means to maintain an enclosure at a low gas pressure, said enclosure including an electrode arrangement having a hollow, open-ended cylindrical anode and a cathode adjacent one open end of the anode. Means are provided to apply potential to the anode and cathode such that during operation a glow discharge takes place. The electrodes forming the electrode arrangement are shaped and positioned so that a stream of electrons which tend to be focused by the electric field associated with the electrode arrangement is derived from the discharge.

This invention relates to cold cathode, glow discharge devices, and method of using such devices.

More particularly the invention relates to novel cold cathode, glow discharge devices, from which an electron beam can be derived. Such devices may be used for a variety of purposes, of which micromachining may be mentioned by way of example; other uses being referred to subsequently.

According to the present invention, a cold cathode, glow discharge device comprises an enclosure, means to maintain the enclosure at a low gas pressure, an electrode arrangement mounted within the enclosure, the electrode arrangement including a hollow, open-ended cylindrical anode and a cathode adjacent one open end of the anode, and means to apply potentials to the anode and cathode such that during operation of glow discharge takes place, the electrodes forming the electrode arrangement being so shaped and positioned that there is derived from the discharge a stream of electrons, which stream tends to be focussed by the electric fields associated with the electrode arrangement.

The anode need not be circular cylindrical, but may for example be of rectangular cross-section. The stream of electrons produced may therefore be a pencil beam which can be brought to a point focus, or a sheet of electrons which can be brought to a line focus.

According to a feature of the present invention, a cold cathode, glow discharge device comprises an enclosure, means to maintain the enclosure at a low gas pressure, an electrode arrangement mounted within the enclosure, the electrode arrangement including a hollow, open-ended cylindrical anode, a cathode adjacent one open end of the anode and a biasing electrode adjacent the side of the cathode remote from the anode, and means to apply operating potentials to the anode, cathode and biasing electrode such that during operation a glow discharge takes place, the electrodes forming the electrode arrangement being so shaped and positioned that there is derived from the discharge a stream of electrons, which stream tends to be focussed by the electric fields assocciaed with the electrode arrangement.

Means may also be included to modulate and/or deflect the stream of electrons. As before the anode need not be circular cylindrical.

Devices as set out above may be used, for example, for the machining of refractory materials such as ceramics; or for the micromachining of materials such as metals, semiconductors or ceramics in the manufacture of electronic microcircuits. In such cases the stream of electrons is brought to a suitably defined focus, using if necessary some magnetic focussing arrangement to supplement the focussing action of the electrode arrangement. The position of the focus is then moved over the material to be machined, for example under the control of a programme, to effect the required removal of material. Additionally the stream of electrons may, if necessary, be modulated, and this also may be under the control of the programme.

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

FIGURE 1 shows diagrammatically the electrode arrangement of a previously proposed device,

FIGURES 2, 4, 5, 6, 7, 8 and 9 show diagrammatically the electrode arrangement of the aforesaid seven devices respectively,

FIGURE 3 shows a graph used in explaining the operation of the device of FIGURE 2,

FIGURE 10 shows diagrammatically the electrode structure of a furnace including several of the devices of FIGURE 4,

FIGURE 11 shows diagrammatically a micromachining apparatus including one of the devices of FIGURE 9, and

FIGURE 12 shows diagrammatically a machining apparatus including a modified version of the device of FIGURE 9.

Referring to FIGURE 1 of the drawings, this shows diagrammatically the electrode arrangement of a previously proposed device. The electrode arrangement comprises a hollow, circular cylindrical anode 1 which is closed at one end, and a cathode 2 adjacent the open end of the anode 1.

The electrode arrangement is supported within an enclosure which is evacuated to a gas pressure of a few microns of mercury. When suitable operating potentials are applied to the anode 1 and cathode 2 a glow discharge takes place, and a stream 3 of electrons passes towards the closed end of the anode 1. The equipotentials 4 and the electric field lines 5 are indicated by broken lines. The stream 3 of electrons tends to diverge towards the closed end of the anode 1.

Referring now to FIGURE 2 of the drawings, this shows diagrammatically the electrode arrangement of a first device in accordance with the invention. The electrode arrangement comprises a hollow, circular cylindrical anode 6 which is open at both ends, adjacent one of the open ends is a cathode 7 and a biasing electrode 8. The cathode 7 and biasing electrode 8 are both planar, normal to the axis of the anode 6, and symmetrically disposed relative to the anode 6; and the cathode 7 has in it a central aperture 9. All the electrodes are stainless steel plates, although clearly other suitable materials may be used.

The electrode arrangement is supported within a glass or glass and metal enclosure (not shown) of known form which contains a suitable gas, for example air, argon, hydrogen or helium, at a pressure of a few microns of mercury. The desired pressure is maintained by pumping the enclosure continuously, whilst at the same time leaking the desired gas in through a valve which is set so as to give the desired gas pressure in the enclosure.

The electrodes are connected to sources of potential so that during operation the anode 6 is maintained at a large positive potential, say 1 to 20 or even 100 kilovolts, relative to the cathode 7 which is earthed. The biasing electrode 8 is maintained at a comparatively low potential, say 0 to 100 volts, positive or negative relative to the cathode 7.

The operation will be described with reference also to FIGURE 3 of the drawings which shows graphically the relation between the electron beam current (ordinates) and the potential of the biasing electrode 8 (abscissae).

A glow discharge takes place between the anode 6 and cathode 7 because electrons from the cathode 7 ionise gas within the anode 6 and some of the positive ions so created strike the cathode 7 and release more electrons. The ion bambardment of the cathode 7 is concentrated about its centre i.e., the intersection of the axis of the anode 6 with the cathode 7. The nature of the glow discharge is essentially similar to that of the well known "Canal Ray Discharge" employed to generate a stream of ions passing through a cathode canal. Some of the positive ions pass through the aperture 9 and ionise the gas in the space between the cathode 7 and the biasing electrode 8. A plasma tends to form in this space (i.e., between cathode 7 and electrode 8), the intensity of which depends on several factors, particularly the separation between cathode 7 and biasing electrode 8 and whether or not a voltage is applied to the biasing electrode 8 in relation to the cathode 7. (If such a voltage is applied, the intensity of the plasma will be increased owing to acceleration and multiplication of free electrons present in the plasma.) Some free electrons present in this plasma find their way, by diffusion, to the aperture 9 in the cathode 7. They may then pass through the aperture 9 to enter the region contained by the anode 6 and cathode 7. In this region they are accelerated by the electric field between the anode 6 and cathode 7 to form an electron beam 10 travelling along the axis of the anode 6, although diverging slightly as the open end of the anode 6 remote from the cathode 7 is approached.

It is to be noted that electrons originating from the cathode 7, cause by its bombardment with ions, tend to travel obliquely to the axis of the anode 6, and many ultimately strike the anode 6. However the electron beam emerging from the aperture 9 and accelerated along the axis of the anode 6 is distinct from these electrons and passes out of the open end of the anode 6 remote from the cathode 7.

The number of electrons passing through the aperture 9 from the plasma between the cathode 7 and biasing electrode 8 depends on several factors, but particularly on the diameter of the aperture 9 and the magnitude and polarity of any voltage applied to the biasing electrode 8. If this voltage is sufficiently positive with respect to the cathode 7 the passage through aperture 9 of electrons from the plasma between cathode 7 and biasing electrode 8 is prevented. This is brought about by the appearance of a space charge sheath at the cathode 7 on the side facing the biasing electrodes 8. If not voltage, or only a small voltage is applied to the biasing electrode 8 the sheath dimension is less than the radius of the aperture 9 and electrons approaching the aperture 9 axially can drift through. When the voltage applied to the biasing electrode 8 is sufficiently positive the dimension of the space charge sheath becomes equal to or greater than the radius of the aperture 9 and no electrons present in the plasma between cathode 7 and biasing electrode 8 can drift through. No axial beam 10 of electrons then passes up the anode 6 although some electrons initiated at the cathode 7 may emerge from the open end of the anode 6 remote from the cathode 7.

A rather similar situation can occur under some conditions when a sufficiently negative voltage is applied to the biasing electrode 8. In these circumstances the electron current emerging from the open end of the anode 6 remote from the cathode 7 varies with voltage applied to the biasing electrode 8 within a limited range as indicated in FIGURE 3. The values V_n and V_p of the extremes of the biasing electrode 8 voltage, in which beam current 10 variation appears, are indicated. At values of voltage more negative than V_n and more positive than V_p the electron current emerging from the open end of the anode 6 remote from the cathode 7 is independent of biasing electrode 8 voltage and contains no axial beam 10. In a particular case V_n was about minus 100 volts and V_p about plus 50 volts. However, these values vary in dependence upon many factors, in particular the spacing between the cathode 7 and the biasing electrode 8, the diameter of the aperture 9, the types of gas, the gas pressure, the anode voltage, etc.

The conditions which give rise to the behaviour indicated in FIGURE 3 involve a relatively small aperture 9 and relatively short spacing of the bias electrode 8 from the cathode 7. When these are increased sufficiently the characteristic at negative bias electrode 8 voltage changes completely and no critical value V_n exists. However a critical positive value V_p exists under all conditions. This change in characteristic behaviour is associated with oscillations in the glow discharge at bias electrode 8 voltage less than V_p. To obtain stable beam conditions with the characteristic typified by FIGURE 3 requires a proper choice of aperture 9 diameter and spacing of bias electrode 8 from the cathode 7. In a particular case, giving the characteristic of FIGURE 3, the diameter of the aperture 9 was one fifteenth the diameter of the anode 6 and the spacing of the bias electrode 8 from the cathode 7 was one third the diameter of the anode 6.

Within the limits of V_n and V_p an electron beam 10 is produced, the electrode configuration, and the shape of the equipotentials 11 and electric field lines 12 (shown in FIGURE 2 for the case where the potential of the biasing electrode 8 is positive), being such that the beam 10 tends to be focused to some extent. The beam current can be modulated by varying the potential of the biasing electrode 8, the maximum frequency of modulation being determined primarily by the finite transit times of the ions formed inside the anode 6 and hence on the distance between the cathode 7 and the anode 6.

Referring now to FIGURE 4 of the drawings, this shows diagrammatically the electrode arrangement of a second device in accordance with the invention. Where possible the same reference numerals are used as previously. The electrode arrangement comprises an anode 6 and a cathode 13, there being no biasing electrode. The cathode 13 is generally planar but has a central well 14. Apart from these points the second device is similar to the first device (FIGURE 2).

During operation an electron beam 10 is produced, the electrons forming the beam 10 resulting from positive ions striking the central region of the cathode 13. Focussing of the electron beam 10 occurs in this case because of the modification to the shape of the equipotentials 11 and electric field lines 12 resulting from the presence of the well 14. The combination of hollow anode 6, planar cathode 13 and well 14 acts as an electrostatic immersion lens of well known properties, the action of which is influenced only slightly by the presence of fast ions bombarding the cathode well 14. The lens has a strong action however, in influencing the trajectories of the electrons emitted from the cathode well 14 under ion bombardment. The focus of the immersion lens is mainly dependent on the size and depth of the well 14. An electron beam concentrated about the axis of the anode 6 is produced when the depth of the well 14 is about one tenth the diameter of the well 14. The diameter of the well 14 is about one third the diameter of the anode 6. These dimensions may be varied a little without much effect on the shape of the beam 10. With this electrode arrangement the electron beam 10 is not modulated.

Referring now to FIGURE 5 of the drawings, this shows diagrammatically the electrode arrangement of a third device in accordance with the invention. Where possible the same reference numerals are used as previously. The electrode arrangement comprises an anode 6, cathode 7 and biasing electrode 8, just as in the first device (FIGURE 2), but with the addition of a focussing electrode **15** between the anode **6** and the cathode **7.** The focussing electrode **15** is planar and normal to the axis of the anode **6**, and has in it a circular central aperture **16** of larger diameter than the aperture **9.**

Neglecting the focussing electrode **15**, the operation of this third device is the same as that of the first device (FIGURE 2), and as in the first device the beam current can be modulated. However, the geometrical arrangement of the focusing electrode **15** and cathode **7** now favours the formation of a focused electron beam and applies the principle embodied in the second device (FIGURE 4). In addition, by applying a potential, which may be positive or negative, to the focussing electrode **15** the degree of focus of the electron beam **10** can be varied as desired.

Referring now to FIGURE 6 of the drawings, this shows diagrammatically the electrode arrangement of a fourth device in accordance with the invention. Where possible the same reference numerals are used as previously. The electrode arrangement comprises an anode **6**, biasing electrode **8** and a focussing electrode **15.** In this case, however, a cathode **17** in the form of a planar circular disc of slightly smaller diameter than the aperture **16** is used.

The operation of this fourth device is very similar to that of the third device (FIGURE 5) except that the ions and electrons entering and leaving the space between the cathode **17** and the biasing electrode **8** pass around the cathode **17** instead of through an aperture in it.

Referring now to FIGURE 7 of the drawings, this shows diagrammatically the electrode arrangement of a fifth device in accordance with the invention. Where possible the same reference numerals are used as previously. The electrode arrangement comprises an anode **6**, biasing electrode **8** and a cathode **17.** The place of the focussing electrode **15** of the third and fourth devices (FIGURE 5 and 6) is taken by a pair of deflecting electrodes **18** and **19** which are similar to one another but are not electrically connected.

The operation of this fifth device is the same as that of the fourth device (FIGURE 6) so long as both the deflecting electrodes **18** and **19** are maintained at the same potential. If however the deflecting electrodes **18** and **19** are at different potentials the electron beam **10** is deflected, FIGURE 7 showing the deflection resulting from the deflecting electrode **18** being at a more positive potential than the deflecting electrode **19.** Thus by applying varying potentials to the deflecting electrodes **18** and **19**, the electron beam **10** can be caused to scan. The rate of scan can be very high as there is no frequency limit imposed by the ions.

By providing a suitable aperture in the path of the electron beam **10**, and causing the electron beam **10** to scan as described above, the electron beam **10** can be switched or modulated as desired. In addition, the device can be modified so as to have an apertured cathode similar to the third device (FIGURE 5).

Referring now to FIGURE 8 of the drawings, this shows diagrammatically the electrode arrangement of a sixth device in accordance with the invention. Where possible the same reference numerals are used as previously. The electrode arrangement comprises an anode **6**, biasing electrode **8** and a focussing electrode **15.** In this case, however, a cathode **20** is formed by the end of a stainless steel rod. The rod projects through an aperture **21** in the biasing electrode **8.** The cathode **20** may be flat initially although sputtering tends to make it become concave with use. In some cases therefore it may be preferable for the cathode **20** to be rounded initially, as this shape tends to be preserved by sputtering.

The operation of this sixth device is generally similar to that of the fourth device (FIGURE 6), but the form of the cathode **20** enables the emitting area to be made very small if desired, and therefore tends to give a better focussed beam **10** of electrons.

The sixth device may be modified by replacing the focussing electrode by two deflecting electrodes, similar to the electrode **18** and **19** of the fifth device (FIGURE 7), so enabling the electron beam **10** to be scanned.

Additionally or alternatively the cathode **20** can be made axially movable for the purpose of varying the degree of focus of the electron beam **10.**

Referring now to FIGURE 9 of the drawings, this shows diagrammatically the electrode arrangement of a seventh device in accordance with the invention. Where possible the same reference numerals are used as previously. The electrode arrangement comprises an anode **6** and a cathode **22** which is in the form of a flat plate. Between the anode **6** and cathode **22** is a control electrode **23** which is similar in position and form to the focussing electrode **15** of the third device (FIGURE 5), but performs in addition the function of modulating the electron beam **10** when a varying potential is applied to it. The control electrode **23** has a control aperture **24** of somewhat smaller diameter than the cathode **22.** With this arrangement few ions pass the cathode **23** and no biasing electrode is necessary.

The operation of this device is generally similar to that of the fourth device (FIGURE 6) apart from the absence of effects due to a biasing electrode.

In the seventh device the cathode **22** can be made rotating, in which case it is made larger and is mounted on an axis off-set from the centre of the aperture **24** in the control electrode **23.** This spreads the erosion over the surface of the cathode **22** and prolongs the life. Still more surface area of the cathode **22** can be used if the axis is made movable.

In all the devices described it may be desirable to have an additional electrode surrounding the anode and maintained at earth potential so that it reduces the tendency for an unwanted Paschen discharge outside the anode.

In addition, in all the devices described the electron beam **10** may be further focussed or deflected by other suitable electrodes or other known means such as magnetic lenses and magnetic or electrostatic deflection arrangements.

For simplicity all the devices have been described as being of circular cylindrical cross-section so that a pencil beam of electrons is produced which may be brought to a point focus. All the devices may however be made of rectangular cross-section so that the beam of electrons becomes a sheet of electrons which may be brought to a line focus.

Devices in accordance with the present invention may be used in many different ways, a few of which will be briefly mentioned.

The first device (FIGURE 2) may be used as a "three electrode" amplifier by arranging that the electron beam **10** is collected on a further electrode (not shown) which is maintained at a suitable positive potential. One possible use of such a device is as the impedance element in a voltage stabiliser circuit, the impedance of the device varying in dependence upon the level of a control signal applied to the biasing electrode **8.**

The first device (FIGURE 2) may be used to excite a gas laser in such a way that the light output of the laser is modulated.

The second to seventh devices may be used to produce the electron beam in a cathode ray tube, so avoiding the need for a thermionic cathode.

The second to seventh devices may also be used to produce electron beams for heating metals, ceramics, and other materials, to extremely high temperatures for any desired purpose. Due to the intense heat fluxes available and the adaptability of the devices to a variety of geometries there is little limit to the size or refractoriness of specimens to be heated.

Referring to FIGURE 10 of the drawings, this shows several of the second devices (FIGURE 4) arranged to provide a furnace for heating a rod 25 by electron bombardment. Where possible the same reference numerals are used as previously. There are in fact six of the devices, so there are six interconnected anodes 6 and six interconnected cathodes 13. Each of the devices is of rectangular cross-section and provides a sheet 26 of electrons which is brought to a line focus on the rod 25.

An improved version of the furnace shown in FIGURE 10 could be constructed using the principle illustrated in the third device (FIGURE 5). Thus the six recessed cathodes of FIGURE 10 would be replaced by slit cathodes with focussing electrodes and biasing electrodes. This arrangement would reduce contamination of the furnace with sputtered atoms from the cathode.

In all casese where a device is used with a large beam current there may be unwanted heating of the electrodes, particularly the biasing electrode, by ion bombardment. This can be reduced by making the relevant electrode apertured. Devices with apertured electrodes can be employed to generate a beam of ions and fast neutral atoms provided the apertured bias electrode is suitably biased positively. The ions can be brought to a point or line focus and their intensity modulated as for the electron beam; they can also be deflected with magnetic fields.

Referring to FIGURE 11 of the drawings, this shows one of the seventh devices (FIGURE 9) arranged for micro-machining a body 27 which may be of metal, semiconductor, or ceramic, or some combination thereof and which is to form an electronic microcircuit. The electrode arrangement of the device comprises, as before, an anode 6, a cathode 22 and a control electrode 23. This electrode arrangement is mounted near one end of a metal, or metal and glass enclosure 28, the body 27 being mounted near the other end.

The enclosure 28 is evacuated by a pump 29, and gas is admitted under the control of a valve 30 from a gas supply 31, so that the desired gas pressure is maintained in the enclosure 28.

The cathode 22 is earthed, and suitable operating potentials derived from a power supply 32 are applied to the anode 6 and control electrode 23, so that an electron beam 33 is produced. The beam 33 is focussed by an electromagnetic focussing coil 34 and then passes through a baffle 35 which reduces contamination of the electrodes 6, 22 and 23 of the device by vapour from the body 27. The beam 33 then passes through two pairs of electromagnetic deflecting coils, one pair of coils 36 of which is shown, and is then focussed on the body 27 by a further electromagnetic focussing coil 37.

To effect the required removal of material from the body 27, the intensity of the electron beam 33 is varied as required by varying the potential applied to the control electrode 23, and the focus of the beam 33 is caused to trace out the required path on the surface of the body 27 by varying the deflecting signal supplied to the two pairs of deflecting coils 36. These two controls are conveniently effected by a programme, so that all the required machining operations on a surface of the body 27 are done in sequence. The next body 27 is then placed in position or the existing body 27 turned to present another surface to the beam 27. Either or both these operations may be arranged to be done without opening the enclosure 28 to atmosphere. As, however, the vacuum required is quite rough, no great delay is involved when the enclosure 28 does have to be opened to atmosphere.

Referring to FIGURE 12 of the drawing, this shows an extension of the seventh device (FIGURE 9) such that an electron beam 38 of great intensity can be formed for melting or machining a comparatively large body 39 of refractory material, such as ceramic. The electrode structure comprises an anode 40, cathode 41 and control electrode 42 which are similar in function to the anode 6, cathode 22 and control electrode 23 of the seventh device (FIGURE 9). The shape of the anode 40, cathode

41 and control electrode 42 may be understood by considering that the lines shown in FIGURE 12 as indicating the electrode arrangement are rotated about the symmetrical axis to trace out complete surfaces of revolution.

The electron beam 38 is therefore generally conical and is focussed by inner and outer focussing coils 43 and 44. Further focussing coils with baffles may be employed to minimise contamination of the electrodes by vapour from the target material.

Still further uses of the devices include type setting by machining from a block, shaping optical lenses by machining, use in X-ray devices, use in the generation of plasma oscillations, use for electron beam welding, and use in any application where intense but controlled heating is required (such as annealing, heat treating, melting, evaporating, crystal growing, and refining of materials).

I claim:

1. A cold cathode, glow discharge device comprising an enclosure, means to maintain the enclosure at a low gas pressure, an electrode arrangement mounted within the enclosure, the electrode arrangement including a hollow, open-ended cylindrical anode and a cathode adjacent one open end of the anode, and means to apply potentials to the anode and cathode such that during operation a glow discharge takes place, the electrodes forming the electrode arrangement being so shaped and positioned that there is derived from the discharge a stream of electrons, which stream tends to be focussed by the electric fields associated with the electrode arrangement.

2. A device in accordance with claim 1 wherein the cathode is planar except for a central well therein, the bottom of the well being planar and parallel to the general plane of the cathode.

3. A cold cathode, glow discharge device comprises an enclosure, means to maintain the enclosure at a low gas pressure, an electrode arrangement mounted within the enclosure, the electrode arrangement including a hollow, open-ended cylindrical anode, a cathode adjacent one open end of the anode and a biasing electrode adjacent the side of the cathode remote from the anode, and means to apply operating potentials to the anode, cathode and biasing electrode such that during operation a glow discharge takes place, the electrodes forming the electrode arrangement being so shaped and positioned that there is derived from the discharge a stream of electrons, which stream tends to be focussed by the electric fields associated with the electrode arrangement.

4. A device in accordance with claim 3 wherein the cathode and the biasing electrode are planar, the anode is right circular cylindrical, and the cathode has a central circular aperture symmetrically disposed relative to the anode.

5. A device in accordance with claim 4 wherein a further electrode is disposed between the anode and the cathode, the further electrode being planar and having a central circular aperture symmetrically disposed relative to the anode, and means is provided to applying a variable operating potential to the further electrode whereby the focus of said stream of electrons may be varied.

6. A device in accordance with claim 3 wherein the cathode and the biasing electrode are planar, the anode is right circular cylindrical, and a further electrode is disposed between the anode and the cathode, the further electrode being planar and having a central circular aperture symmetrically disposed relative to the anode, and means is provided to apply a variable operating potential to the further electrode whereby the focus of said stream of electrons may be varied.

7. A device in accordance with claim 3 wherein the cathode and biasing electrode are planar, the anode is right circular cylindrical, two further electrodes are disposed between the anode and the cathode, the further electrodes being planar, similar, and lying in the same plane in symmetrical positions relative to the anode, and means is provided to apply variable and different operat-

ing potentials to the two further electrodes whereby said stream of electrons may be caused to scan.

8. A device in accordance with claim **3** wherein the anode is right cylindrical, the cathode is formed by the end of a rod disposed on the axis of the anode, said rod projecting through an aperture in the biasing electrode such that the cathode is adjacent to but outside the anode, a further electrode is disposed between the anode and the cathode, the further electrode being planar and having a central circular aperture symmetrically disposed relative to the anode, and means is provided to apply a variable operating potential to the further electrode whereby the focus of said stream of electrons may be varied.

9. A cold cathode, glow discharge device comprises an enclosure, means to maintain the enclosure at a low gas pressure, an electrode arrangement mounted within the enclosure, the electrode arrangement including a hollow, open-ended cylindrical anode, a cathode adjacent one open end of the anode and a control electrode disposed

between the cathode and the anode, means to apply operating potentials to the anode and cathode such that during operation a glow discharge takes place, the electrodes forming the electrode arrangement being so shaped and positioned that there is derived from the discharge a stream of electrons, which stream tends to be focussed by the electric fields associated with the electrode arrangement, and means to apply a variable potential to the control electrode whereby the intensity of said stream of electrons may be varied.

10. A device in accordance with claim **9** wherein means is provided external to the electrode structure further to focus said stream of electrons, and means is also provided external to the electrode structure to deflect said stream of electrons.

No references cited.

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