

Nov. 16, 1965

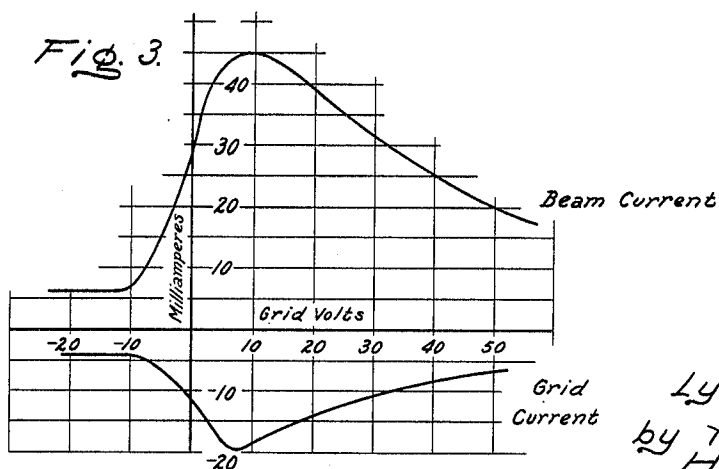
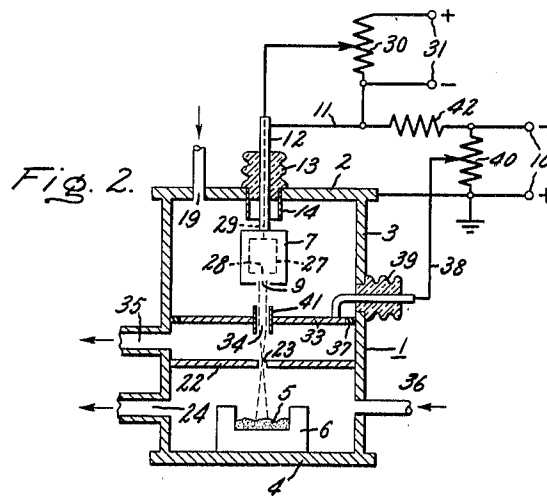
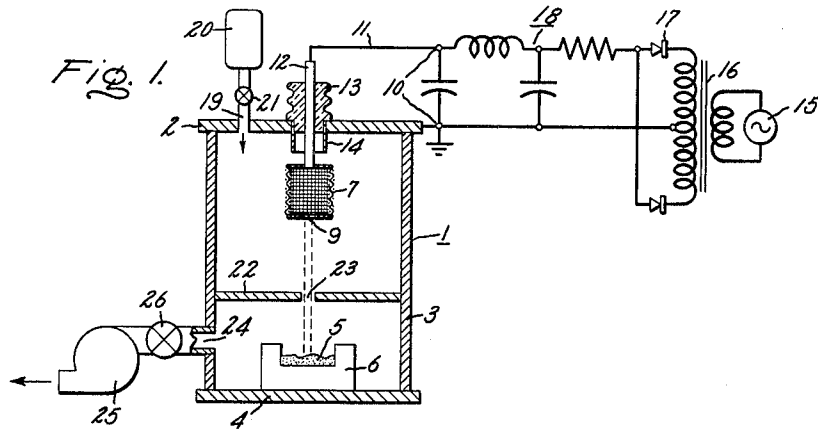
L. H. STAUFFER

3,218,431

SELF-FOCUSING ELECTRON BEAM APPARATUS

Filed Dec. 27, 1962

2 Sheets-Sheet 1



Inventor:
Lynn H. Stauffer,
by Paul G. Frank
His Attorney.

Nov. 16, 1965

L. H. STAUFFER

3,218,431

SELF-FOCUSING ELECTRON BEAM APPARATUS

Filed Dec. 27, 1962

2 Sheets-Sheet 2

Fig. 6.

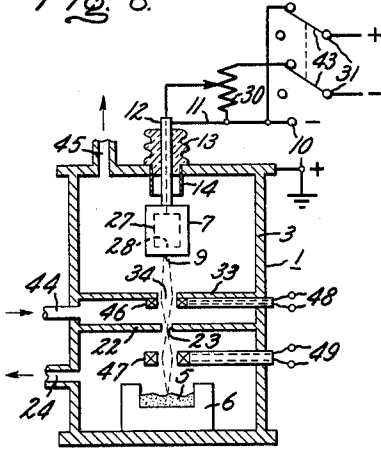


Fig. 4.

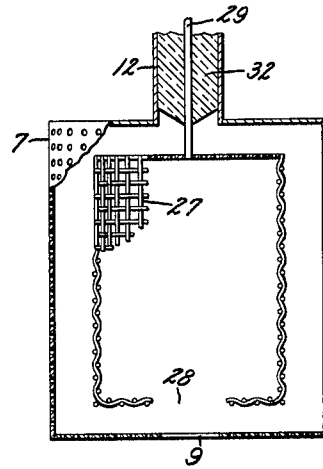


Fig. 7.

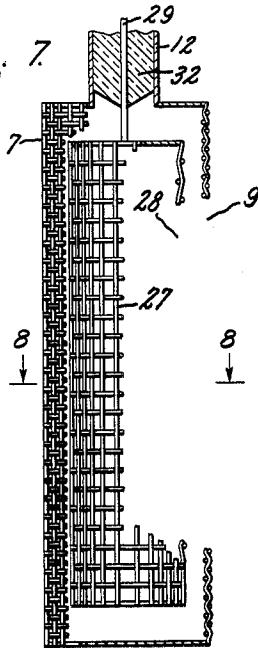


Fig. 5.

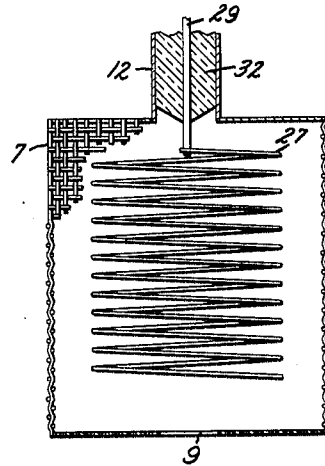
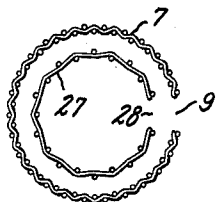


Fig. 8.



Inventor:
Lynn H. Stauffer;
by Paul A. Frank
His Attorney.

1

3,218,431

SELF-FOCUSING ELECTRON BEAM APPARATUS
Lynn H. Stauffer, Pattersonville, N.Y., assignor to
General Electric Company, a corporation of New York
Filed Dec. 27, 1962, Ser. No. 247,730
12 Claims. (Cl. 219—121)

My invention relates to certain improvements in electron beam irradiation apparatus of the gaseous beam type whereby the intensity of the beam may be more effectively controlled than heretofore.

One form of gaseous electron beam apparatus, as now known, comprises a hollow cathode structure having perforated sidewalls arranged within a housing filled with a low pressure ionizable gas and maintained at high negative potential relative to the housing. In operation, a plasma of ionizable gas forms within the cathode from which, due to said potential and interaction of the plasma and side walls of the cathode structure, a beam of electrons is emitted from the cathode through an aperture formed in a wall thereof. This beam may be caused to fall upon material to be irradiated which may be at the more positive potential of the housing and exposed to the ionizable gas.

One shortcoming of this apparatus is the inability to prevent contamination of the cathode by gases or vapors which may be generated by excessive gassing of the material being irradiated, thereby decreasing the life of the cathode.

Another shortcoming in such apparatus is the inability to control the intensity or magnitude of current in the beam without affecting its focus and without variation of said high potential or gas pressure.

An object of my invention is to obviate these shortcomings and to provide means to vary the intensity of the beam over a wide range without affecting its focus and independently of the negative operating voltage and gas pressure.

A further object of my invention is to effect such control by varying a relatively small voltage applied between a control electrode structure arranged in accord with my invention and the cathode structure to thereby effect such control largely with facility characteristic of other types of discharge devices.

In accord with my invention, a control electrode is arranged within the cathode structure, shaped in general conformity to that structure and spaced from its side walls and insulated therefrom. This control electrode may be connected to a suitable low voltage source by which its potential relative to the cathode structure may be varied in either the positive or negative direction over a desired range thereby to vary the current in the beam. I believe that the operation of the control electrode so arranged is to control the electron density in the plasma which is enclosed by the control electrode, thereby controlling the current in the beam issuing from the plasma through aligned apertures in both the control electrode and cathode structure. The electron beam thus produced is especially useful in high quality metal working such as cutting, welding, brazing and also in fusing dissimilar materials including refractory substances such as porcelain to tantalum wherein high processing temperatures in the order of 3000° C. are required.

The features of my invention which I desire to protect herein are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings, wherein like parts in each of the several figures are identified by the same reference character, and wherein:

2

FIGURE 1 is an elevation view, partly in section, illustrating an electron beam irradiation apparatus constructed in accordance with my invention;

FIGURE 2 is an elevation view, partly in section, illustrating a first embodiment of an electron beam irradiation apparatus employing a control electrode and electrostatic beam focusing means;

FIGURE 3 shows a series of current versus control electrode voltage characteristic curves illustrating the control obtained in accordance with my invention;

FIGURE 4 is a detail view of a first embodiment of the cathode and control electrode structure arrangement shown in FIGURE 2;

FIGURE 5 is a detail view of a second embodiment of a cathode and control electrode structure arrangement;

FIGURE 6 is an elevation view, partly in section, illustrating a second embodiment of an electron beam irradiation apparatus employing a control electrode and electromagnetic beam focusing means;

FIGURE 7 is a detail view of a cathode and control electrode structure arrangement whereby an electron beam having a rectangular cross section may be produced; and

FIGURE 8 is a cross sectional view of the cathode and control electrode structure arrangement taken on the plane of line 8—8 of FIGURE 7.

Referring particularly to the apparatus illustrated in FIGURE 1, there is shown a housing designated as a whole by numeral 1, preferably of cylindrical shape although other forms may also be employed. Housing 1 is constructed of an electrically conductive material that is nonporous and preferably metallic and as illustrated, comprises a top end plate 2, hollow cylindrical wall 3, and bottom end plate 4. Top end plate 2 is joined to cylindrical wall 3 by any well known metal to metal joining method, the particular method not being critical since a high vacuum is not required therein. Bottom end plate 4 or a lower section of cylindrical wall 3 is made removable to facilitate the insertion and withdrawal of material 5 being processed in container 6 which rests on bottom end plate 4. Container 6 may be made of copper or other suitable good electrically conductive and good heat conductive material and the anode of the apparatus is then considered as comprising housing 1 and container 6.

The electron source consists of a hollow cathode structure 7, preferably in the form of a cylinder although other shapes may be employed, with an aperture 9 in the center of a bottom end wall thereof wherefrom an electron beam is emitted by nonthermionic means in a manner to be described in detail hereinafter. This hollow cathode structure 7 is constructed from an electrically conductive material which must be capable of being formed, have a relatively high melting point to avoid melting at the red heat temperature to which the cathode may be subjected at high beam intensities even though no heat source as such is utilized, preferably not emit significant amounts of gas at this temperature, and have relatively high secondary electron emission characteristics. A preferred embodiment of the cathode is constructed from a perforated sheet or mesh of molybdenum, although other surfaces characterized by a number of small opening therethrough are also appropriate. The cathode may also be constructed of stainless steel or copper by way of further example. Although the top and bottom end walls of the cathode may be constructed of solid electrically conductive material, they are preferably made of the same perforated material as the cylindrical wall thereof.

A power supply line connected to terminals 10 supplies an adjustable voltage of relatively high negative direct current potential to cathode 7 relative to housing 1 by means of conductor 11 and cathode stem 12 con-

3

nected thereto. The positive or ground side of the power supply line is connected to the anode or housing 1. Cathode stem 12 is insulated from top end plate 2 by means of insulating bushing 13 and comprises a hollow tubular electrically conductive member, preferably made of stainless steel, that supports cathode 7 and positions it within housing 1, and also provides a passage means for an electrical conductor to be described hereinafter in relation to FIGURE 2. A hollow tubular electrically conductive shield 14, concentric with cathode stem 12 and spaced therefrom is positioned along the upper portion of stem 12 contained within housing 1 and in good electrical contact therewith to prevent long-path discharge between the cathode stem and top end plate 2. The high voltage supplied at terminals 10 is adjustable up to 20 kilovolts or more and may be provided by a power supply consisting of adjustable alternating current voltage source 15, whose voltage is increased by means of step-up transformer 16 and then converted to a filtered direct current voltage by means of rectifiers 17 and a conventional filter network illustrated as a whole by numeral 18 and which may include resistors, inductors, and capacitors.

A suitable ionizable gas, such as argon or helium, is introduced into the interior of the enclosure within housing 1 that surrounds cathode 7 through passage means 19 which may pass through top end plate 2 or the upper portion of side wall 3. Passage means 19 is connected to a gas supply 20 through valve 21 which regulates the rate of gas flow into housing 1. A partitioning member 22, nonporous to the gaseous medium and which may be made of the same material as housing 1, separates the housing into two enclosures, the first or upper enclosure enclosing the cathode and the second or lower enclosure containing the material being irradiated and processed by an electron beam emitted by the cathode. An aperture 23, within partitioning member 22 and aligned with cathode aperture 9, is of size sufficient merely to permit passage of the electron beam therethrough and insufficient in size to permit objectionable passage of any gases or vapors which may be generated by excessive gassing of the irradiated material 5 in the lower or processing enclosure. A second passage means 24 located in the lower enclosure provides, by virtue of its large size, a low impedance exit for this generated gas and thus aids in maintaining a desired gas pressure within the upper or cathode enclosure, and is connected to a suitable exhaust pumping device 25 through throttle valve 26. Thus, possible contamination of the cathode by undesired gases generated by the irradiated material is largely prevented by employing the particular partitioning member described. Further, the partitioning member aids in maintaining a desired low gas pressure in the cathode enclosure and thereby maintain the electron beam in a collimated mode.

One theory for explaining the principle of electron beam formation and ejection from a hollow perforated cathode is as follows: The interior of the cathode cavity comprises a glowing body of plasma or ionized gas, separated from the cathode walls by a less luminous sheath which is bounded by said walls. Positive ions and free electrons comprise main constituents of the plasma. The potential distribution inside the cathode comprises equipotential surfaces that extend through cathode aperture 9, thereby crowding together at the aperture and effecting a high voltage gradient which extracts electrons from the internal plasma and initiates an electron beam. An external glow discharge or plasma surrounding the cathode determines an ionized region of low voltage drop, separated from the cathode by a sheath or dark space in which a large voltage drop occurs. Since the cathode potential may be 5 to 20 kv. negative with respect to the anode, positive ions are drawn from the external plasma and accelerate across the dark space to impinge on the outer surface of the cathode or pass inside through the

4

interstices of the perforated cathode. These ions possess several thousand electron volts of kinetic energy and they may release large numbers of electrons by secondary electron emission due to impact with the cathode surface, by ionizing collisions with the gas, and by excitation of atoms by indirect processes which emit photons which, in turn, give rise to photoelectrons at the cathode.

The positive ions drawn from the external plasma and impinging on the outer surface of the cathode release secondary electrons which are repelled from the cathode and ionize the gas in their path by collision. This ionization maintains the external plasma which is the source of positive ions.

Many of the positive ions drawn from the external plasma and passing through the interstices of the perforated cathode strike the inner cathode surface and thereat generate secondary electrons. Each positive ion may generate several secondary electrons which are drawn into the internal plasma and thence from cathode aperture 9 by the strong positive potential gradient existing thereat. If the external field strength is greater than that inside the cathode, the aperture has a converging action on the emerging electron stream, thus explaining why beam collimation is voltage dependent. Due to the continuous extraction of electrons at the cathode aperture, the internal plasma body assumes a positive potential which expels positive ions to the cathode walls. These expelled positive ions, together with incoming secondary electrons, attempt to maintain equilibrium of electrical charge of the internal plasma against the outward drain due to the electron beam. The electron beam is collimated by what may be described as a gas-focusing process when both the gas pressure and cathode potential relative to the anode are maintained within a particular critical range dependent on the gaseous medium utilized. Any inert gas or metallic vapor, as well as hydrogen, may be employed as the gaseous medium contained within the upper enclosure and for best performance from the standpoint of small electron beam cross section and large beam current, a cathode diameter to cathode aperture ratio of approximately 4 to 1 is employed.

Control of the beam intensity, that is, the total current within the electron beam, over a substantial range of beam current may be obtained by simultaneously adjusting the gas pressure and cathode to anode potential. However, the beam is not self-focusing, that is, the beam intensity is not controllable independently of the focus, thus, a significant change in beam intensity produces a poorly focused beam and in the extreme case may cause the cathode discharge to pass out of the beam mode and become a diffuse glow discharge. It can be appreciated that for applications such as welding, or cutting, an electron beam having a high power concentration, that is, a finely focused or collimated beam is generally desired over a wide range of beam intensity control.

The intensity of the beam may be controlled without affecting its focus and without adjustment of the gas pressure and high cathode-to-anode potential, that is, it may be made to maintain its self-focused condition by positioning a control electrode structure shaped in general conformity to the cathode, within said cathode and applying an adjustable potential between said control electrode and cathode. Control electrode 27 is positioned substantially centrally of the cathode and spaced therefrom whereby it is electrically insulated from the cathode. The spacing between cathode and control electrode is preferably approximately 10 percent of the cathode diameter, although this dimension may be varied over a considerable range and is not recited as a limitation. Control electrode 27 is provided with an aperture 28 in the lower end thereof that is substantially concentric with cathode aperture 9. The control electrode structure or grid is preferably constructed of very fine wire and preferably has a surface characterized by a greater open area per unit area of surface than the cathode. However, the control elec-

5

trode structure is not limited by these characteristics, and a smaller open surface and thick wire construction will also control beam intensity, although less effectively. The control electrode may be fabricated from similar material comprising the cathode. The top and bottom end walls of the control electrode structure are preferably constructed of the same relatively open mesh surface as the cylindrical wall thereof to minimize positive ion interception which may occur from all directions. In the alternative, the top and bottom end walls of the control electrode may be completely open. Tubular cathode stem 12 provides a passage means for an electrical conductor 29 that supplies control voltage to control electrode 27. Conductor 29 passes through cathode stem 12 and is electrically insulated therefrom by insulation material which is appropriate to the potential applied between the cathode and anode and also forms a gas-tight seal. Conductor 29 is preferably made of heavy wire to support the control electrode and maintain its position concentrically within the cathode. One end of conductor 29 is electrically connected to a movable arm on potentiometer 30 and a relatively low direct current voltage of approximately 100 volts supplied to terminals 31 is applied across potentiometer 30 to obtain a variable positive or negative potential on the control electrode with respect to the cathode.

The effect of control electrode structure 27 is to control the electron density in the plasma, the plasma being enclosed by the electrode structure and thereby controlling the current in the beam issuing from the plasma through the aligned apertures in both the control electrode and cathode. Maintaining the control electrode potential negative with respect to the cathode repels secondary electrons emerging from the inner cathode surface back toward the surface, thus reducing the supply of electrons available to the beam. Maintaining the control electrode at the same potential as the cathode produces little effect since the relatively open control electrode structure renders it highly transparent to electrons. However, maintaining the control electrode potential positive with respect to the cathode assists the transfer of secondary electrons into the internal plasma which maintains the beam and thereby increases the beam intensity.

Referring particularly to FIGURE 3, it is observed that as the control electrode potential (grid volts) is made increasingly positive with respect to the cathode, the beam current or intensity increases to a maximum and then decreases. This latter effect is believed to be related to the influence of the electric field between the control electrode and cathode on the distribution of positive ions within the cathode. It may be seen from FIGURE 3 that substantially the full range of beam current may be controlled by varying the potential between control electrode and cathode approximately plus or minus 10 volts. This means of controlling the beam current is very efficient since the ratio of watts beam power controlled to watts grid or control electrode power required for this control may be approximately 2000 to 1 or greater. The particular curves illustrated in FIGURE 3 were obtained for a cathode-control electrode arrangement contained in a gaseous medium of argon at 7 microns pressure and a cathode-to-anode potential of 11.0 kv.

The specific cathode and control electrode structure arrangement from which the curves of FIGURE 3 were obtained is shown in the detail view of FIGURE 4. Cathode 7 is shown in the broken section as comprising a hollow perforated cylindrical chamber having a diameter of $1\frac{1}{8}$ inches, a length of $1\frac{1}{2}$ inches, and constructed of perforated stainless steel having 0.2 mm. holes with 15 holes per centimeter. Control electrode 27 comprises a hollow cylindrical body having a diameter of $\frac{7}{8}$ inch, a length of $1\frac{1}{8}$ inches, and constructed of a mesh structure having 32 mesh per inch and made of 0.005 molybdenum wire. It should be understood that the control electrode may also comprise a perforated structure, or both cathode

6

and control electrode may comprise a mesh structure or other relatively open grid-like structures, and these configurations would produce characteristic curves similar to those of FIGURE 3 if the above-recited dimensions were maintained. Electrical insulation 32, appropriate to the cathode-to-anode potential, insulates the control electrode from the cathode and acts as a gas seal and a further support for the control electrode structure.

Referring back to FIGURE 2, a second stage of exhaust pumping is employed as distinguished from the single stage in FIGURE 1. For materials 5 giving off little or no gas during irradiation, very little pumping is necessary and the pumping arrangement illustrated in FIGURE 1 is satisfactory. However, for liquids in film or spray form which are encountered in the sterilization of drug products, chemical synthesis of compounds, and polymerization, or for solids having high vapor pressure, a second stage of exhaust pumping as illustrated in FIGURE 2 is needed. Thus, partitioning member 33 with aperture 34 therein, aligned with the cathode and control electrode apertures and aperture 23, defines an intermediate enclosure contained between partitioning members 22 and 33 and is provided with an exhaust pumping means (not shown) through passage means 35. In this particular application, the exhaust pumping through passage 35 primarily determines the pressure of the gas introduced through passage means 19 within the upper or cathode enclosure, although it also acts as a further impediment, along with the small dimensions of apertures 23 and 34, to the flow of contaminating gas or vapor from material 5 into the upper enclosure.

An additional feature of the apparatus illustrated in FIGURE 2 is the introduction of a second gaseous medium into the bottom or processing enclosure through passage means 36. In applications requiring the irradiation of material 5 in a gaseous atmosphere different from the gas contained in the upper enclosure, as in the case of nitriding steel, the desired gas is introduced into the bottom enclosure and exhausted through passage means 24, the gas supply, pumping and valve devices not being shown. Since apertures 23 and 34 present a high impedance for any gas passage, the second gaseous medium is primarily contained within the bottom enclosure and any slight amount which passes through aperture 23 is exhausted through passage means 35.

An independent focus adjustment of the electron beam may be obtained by electrically insulating partitioning member 33 from the wall of housing 1 by means of insulator 37 and applying an adjustable potential as shown to member 33 by means of conductor 38. Conductor 38 is connected to partitioning member 33 and passes through the housing wall by means of insulating bushing 39 due to the relatively high negative potential impressed on number 33 relative to housing 1. Conductor 38 is connected to the movable arm of potentiometer 40 which in turn is connected across the cathode high voltage supply terminals 10. An electrically conductive cylinder 41 having open ends may be connected to member 33 at aperture 34 to provide a more efficient electrostatic focusing or defocusing of the electron beam. The electrostatic focusing can be adjusted whereby the beam possesses its smallest cross section in passing through aperture 23, thereby permitting a smaller aperture to be used thereat and also, to control the focus of the beam as it comes in contact with the irradiated material 5. Thus, for welding operations, the electrostatic focusing is adjusted to define a very finely focused or high power density beam on the work being welded whereas for a chemical process requiring large area irradiation, the beam is substantially defocused. Ballast resistor 42 is connected in the cathode power supply line for cathode voltage stabilization, it being understood that a similar resistor would likely be employed in FIGURES 1 and 6, although not illustrated therein.

A second embodiment of a cathode control electrode

structure arrangement constructed in accordance with my invention is illustrated in FIGURE 5. In this particular arrangement, cathode 7 is formed of a mesh structure and the control electrode 27 comprises a helically wound coil of wire. The materials from which these structures are constructed may be the same as recited for the arrangement in FIGURE 4.

FIGURE 6 illustrates a second embodiment of an electron beam apparatus containing a cathode and control electrode structure arrangement. In this particular configuration, the control electrode voltage source is connected to terminals 31 and therefrom to potentiometer 30 by means of reversing switch 43. Reversing switch 43 in a first position as shown in FIGURE 6 renders the control electrode potential negative with respect to the cathode. In a second position, illustrated as the extreme lower one, the control electrode potential is rendered positive with respect to the cathode. Switch 43 may also be provided with a neutral position as shown whereby potentiometer 30 is disconnected from terminals 31 and potentiometer 30 now acts as a rheostat, and the control electrode potential may be controlled by a self-biasing arrangement that makes the control electrode positive with respect to the cathode by increasing the resistance in series therewith. In any of the switch positions, the control electrode may be adjusted to the same potential as the cathode by setting the movable arm of potentiometer 30 to the extreme lower position.

Another feature of the apparatus illustrated in FIGURE 6 is the arrangement of the inlet and exhaust passage means passing through the walls of housing 1. The entrance passage means 44 for the gaseous medium to be contained by the upper enclosure is located in the housing wall of the intermediate enclosure. With this arrangement, aperture 34 is made of size sufficient for passage of both the electron beam and the gaseous medium. A passage means 45 provides a gas exhaust from the upper enclosure therein. It is to be understood that entrance passage 44, and exhaust passages 45 and 24 are connected to suitable valves and pumping devices to maintain the desired low gas pressure within the upper enclosure. An advantage of this gas distribution arrangement is that the higher pressure of the gaseous medium within the intermediate enclosure further impedes any undesired gas which may be generated in the lower enclosure from passing into the upper enclosure.

An added feature of the apparatus disclosed in FIGURE 6 is the use of magnetic focusing coils to control the cross section of the electron beam both in passing through aperture 23 in the lower partitioning member 22 and also at the material 5 being irradiated by said beam. In this case, the partitioning members must be constructed of nonmagnetic material. A first electromagnetic coil 46, which may simply be wound on a nonmagnetic spool in concentric relationship to the electron beam and spaced therefrom, is adapted to focus the beam to its smallest cross section as it passes through aperture 23. A second electromagnetic focusing coil 47, similar in construction to coil 46 is positioned in the lower enclosure to control the now diverging electron beam into a finally focused spot on the material 5 being irradiated, or in the alternative, further defocus the beam to provide wide area irradiation. Although coils 46 and 47 may each be connected across a power supply having a high voltage and low current output, I prefer to employ a power supply having a low voltage and high current output whereby the conductors 48 and 49 joining the ends of each coil, respectively, may be brought out through the side walls of housing 1 by merely employing low voltage insulation surrounding said conductors. Electron beam power densities of 10,000 kw./in.² or greater may be obtained by the apparatus hereinabove disclosed.

The cross-sectional shape of the electron beam generated by the cathode and the control electrode structures of my invention is determined primarily by the

geometry of the apertures 9 and 23 in the respective bottom walls thereof. For many applications, these apertures are circular in shape and thereby cause the generation of an electron beam having a circular cross section.

However, in applications such as heat treating a moving sheet of metal, it is desirable to provide a long rectangular beam of concentrated electrons whereby the long dimension thereof may irradiate the full width of the sheet as it passes thereby. To produce the desired electron beam having a long rectangular cross section, apertures 9 and 23 are located in alignment on a cylindrical side of the cathode and control electrode structures, respectively, as illustrated in FIGURE 7. The rectangular shaped aperture is formed therethrough with the long dimension of the rectangle being in the axial direction of the cylindrical structures. The electron beam emitted through apertures 9 and 23 thus has a desired long rectangular cross section.

FIGURE 8 is a plan view on the plane of line 8—8 of FIGURE 7 and illustrates the relative width or short dimension of rectangular apertures 9 and 23, whereas FIGURE 7 indicates their long dimension.

From the foregoing description, it can be appreciated that my invention makes available a new apparatus for irradiating materials by means of an electron beam wherein gases or vapors produced by the material being irradiated are prevented from contaminating or disturbing the focused condition of the beam emitting cathode which is contained in an enclosure separated from the enclosure containing the material being irradiated. It is to be understood that the number of enclosures is not limited and is determined primarily by the controlled atmospheres in which the cathode and irradiated material are to operate. The electron beam is nonthermionically emitted through an aperture in a hollow perforated cathode by interaction of an ionizable gaseous medium maintained at low pressure and a high negative potential maintained at the cathode relative to the anode. This nonthermionic emission permits the cathode to function effectively at low temperatures. The electron beam may maintain self-focusing by providing a control electrode within the cathode. This self-focusing feature permits control of the beam over a wide range of beam power in a simple manner by adjusting a relatively low potential applied between the cathode and the control electrode. Since this control is obtained independently of the beam focus which remains fixed, no adjustment in the pressure of the gaseous medium or in the relatively high potential applied to the cathode relative to the anode, to restore focus, is required. The self-focusing feature, under appropriate conditions of cathode voltage and gas pressure, also permits elimination of the conventional beam focusing techniques normally employed in high vacuum, thermionically emitting electrode electron beam generators, although they may be employed to provide an independent focus adjustment of the beam as dictated by the particular application employing the beam irradiation. Finally, the apparatus may be used for irradiating materials in controlled environments including gaseous mediums different from the gas contained in the cathode enclosure, and may even be used for irradiation in ambient atmospheric conditions, in which case, the processing enclosure would be left open to the ambient air. The irradiated material may be positioned in the last enclosure or an intermediate one.

Having described a new and improved apparatus for generating an electron beam in a low pressure gaseous medium wherein the beam may be controlled over a wide range of beam intensity independently of the beam focus, it is believed obvious that modifications and variations of my invention are possible in the light of the above teachings. Thus, alternating current power or any combination of direct and alternating current power may be applied to the cathode and control electrode structures to obtain a controlled pulsating electron beam. It is,

therefore, to be understood that changes may be made in the particular embodiments as described which are within the full intended scope of the invention as defined by the following claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electron beam generating apparatus comprising:
 - a housing,
 - means for defining a plurality of enclosures within said housing, and
 - a hollow cathode structure having a surface characterized by a number of small openings therethrough, said cathode disposed within a first of said enclosures, means for introducing a low pressure ionizable gaseous medium within said first enclosure, means for operating said cathode at a high negative potential relative to the housing sufficient to produce a plasma within said cathode, said cathode and said enclosure defining means each having an aperture, the apertures aligned with respect to each other whereby an electron beam issuing from the plasma passes through said apertures into another of said enclosures, said other enclosure adapted to utilize said beam which utilization may generate an undesired gaseous medium, the aperture in said enclosure defining means being of size sufficient for passage of the electron beam and insufficient for passage of objectionable amounts of the undesired gaseous medium into said first enclosure.
2. An electron beam generating apparatus comprising:
 - a housing,
 - means for partitioning said housing into a plurality of enclosures,
 - a hollow cathode structure having perforated sides, said cathode positioned in a first of said enclosures and electrically insulated therefrom, means for introducing a low pressure ionizable gaseous medium within said first enclosure, means for providing a high negative potential on said cathode relative to said housing whereby a collimated electron beam issues from a plasma generated within and enclosed by the cathode, said cathode having an aperture through which said beam passes into said first enclosure,
 - said housing partitioning means have an aperture aligned with said cathode aperture whereby said beam passes into another of said enclosures, said other enclosure adapted to utilize said beam which utilization may produce a second gaseous medium, the aperture in said housing partitioning means being of size sufficient for passage of said beam therethrough and insufficient for passage of objectionable flow of second gaseous medium into said first enclosure,
 - means for providing entrance and exit passages for the first and second gaseous mediums, and
 - means for controlling the intensity of the electron beam independently of the focus thereof.
3. The apparatus set forth in claim 2 including:
 - a passage means disposed in a wall of said other enclosure for introducing a controlled gaseous atmosphere within said other enclosure whereby material to be irradiated by said electron beam is subjected to said controlled gaseous atmosphere.
4. The combination of a hollow cathode structure having a perforated surface, means for providing a low pressure ionizable gaseous medium, to the cathode, means for operating the cathode at a high potential relative to the enclosure of said medium sufficient to produce a plasma within the cathode, said cathode having an aperture through which an electron beam issues from the plasma, and
 - means positioned within said cathode and electrically insulated therefrom for controlling the intensity of the electron beam independently of the focus thereof.

5. The combination of a hollow cathode structure having perforated sides, means for providing a low pressure ionizable gaseous medium to the cathode, means for operating the cathode at a high negative potential relative to the enclosure of said medium sufficient to produce a plasma within the cathode, said cathode having an aperture through which an electron beam issues from the plasma, and
 - a control electrode structure positioned within said cathode structure and arranged to enclose said plasma, said control electrode having an aperture aligned with said cathode aperture through which said beam issues whereby the intensity of current in said beam may be varied by varying the potential between said control electrode and cathode structures.
6. The combination of a hollow cathode structure having a surface characterized by a number of small openings, said cathode positioned within an enclosure adapted to contain a low pressure ionizable gaseous medium, means for providing a low pressure ionizable gaseous medium within the enclosure, means for operating said cathode at a high negative potential relative to the enclosure sufficient to generate a plasma within the cathode, said cathode having an aperture through which an electron beam issues from the plasma to the exterior of said cathode, and
 - a hollow control electrode shaped in general conformity to the cathode structure and having a surface characterized by a grid-like structure, said control electrode positioned within and substantially centrally of said cathode and electrically insulated therefrom, said control electrode enclosing said plasma and having an aperture aligned with said cathode aperture through which said beam passes and whereby the magnitude of current in said beam may be varied independently of the beam focus by varying a low potential between said control electrode and cathode.
7. The combination set forth in claim 6 wherein said hollow control electrode comprises a mesh structure.
8. The combination set forth in claim 6 wherein said hollow control electrode comprises a helically wound coil of wire.
9. The combination set forth in claim 6 wherein said hollow control electrode comprises a perforated structure.
10. In an apparatus for irradiating a material with an electron beam having a generally rectangular cross section the combination of,
 - a hollow cylindrical cathode structure having a surface characterized by a large number of small openings, said cathode electrically insulated from and positioned within an enclosure, means for supplying a low pressure ionizable gaseous medium within the enclosure,
 - an electrical conductor connected from said cathode through said enclosure and insulated therefrom, means for supplying a high negative potential to said cathode relative to said enclosure by means of said electrical conductor whereby an interaction of the gaseous medium and potential produces a plasma contained within said cathode, said cathode having a long rectangular shaped aperture in the cylindrical side thereof, the long dimension of said aperture being in the axial direction of the cylindrical structure whereby an electron beam having a rectangular cross section may issue from the plasma and pass through said aperture,
 - a hollow control grid structure having a mesh surface, said control grid positioned within and substantially centrally of said cathode and enclosing said plasma, said control grid electrically insulated from said cathode and having a rectangular shaped aperture aligned with said cathode aperture wherethrough said rectangular shaped beam passes, and

11

- a second electrical conductor connected from said control grid through said enclosure and insulated from said cathode and enclosure, means for supplying a variable low potential to said control grid relative to said cathode by means of said second electrical conductor and thereby control the intensity of the rectangular cross section beam current independently of the beam focus.
11. An electron beam welding apparatus comprising:
- a housing,
 - a pair of nonporous members for partitioning said housing into three enclosures,
 - a hollow cathode structure having perforated sides, said cathode positioned within a first of said enclosures and electrically insulated therefrom, said cathode having an aperture through which an electron beam may pass,
 - means for supplying a controllable high negative potential on said cathode relative to said housing,
 - a hollow control electrode structure shaped in general conformity to the cathode structure and having a surface characterized by a greater open area per unit of surface than said cathode, said control electrode positioned within and substantially centrally of said cathode and electrically insulated therefrom and having an aperture aligned with cathode aperture,
 - a first passage means connected to a source of low pressure ionizable gaseous medium, said first passage means disposed in a wall of said first enclosure whereby a low pressure ionizable gaseous medium may be introduced therein and an interaction of the gaseous medium and negative potential between cathode and housing may produce a plasma enclosed by said control electrode and emission of a collimated electron beam from the plasma through the grid and cathode apertures,
 - means for supplying an adjustable low potential on said control electrode relative to said cathode and thereby provide control of the intensity of the electron beam independently of the beam focus,
 - said partitioning members each having an aperture aligned with said cathode and grid apertures whereby said electron beam passes through a second of said enclosures and into a third enclosure adapted to utilize the power within said electron beam in a welding operation, the apertures in said members being of size sufficient for passage of said beam there-through and insufficient for appreciable passage of a second gaseous medium which may be generated in said third enclosure,
 - a second passage means disposed in a wall of said second enclosure for exhausting gas within said second enclosure and thereby maintaining the ionizable gas in said first enclosure within a relatively narrow low pressure range and further impeding passage of the second gaseous medium into said first enclosure,
 - a third passage means disposed in a wall of said third enclosure for exhausting said second gaseous medium which may be generated by material being welded by said electron beam in said third enclosure,
 - a first electromagnetic coil positioned within said second enclosure substantially concentric to said electron beam and spaced therefrom whereby the electron beam may be controllably focussed to a very small cross section as it passes through the aperture in the partitioning members separating the second and third enclosures, and
 - a second electromagnetic coil positioned in said third enclosure substantially concentric to said electron beam and spaced therefrom for controlling the focus

12

- of the electron beam on material being welded in said third enclosure, said first and second electromagnetic coils having their ends passing through the sides of said housing whereby an adjustable voltage may be impressed across each coil.
12. An electron beam irradiating apparatus comprising:
- a housing,
 - a pair of nonporous partitioning members disposed within said housing whereby three enclosures are defined therein,
 - a hollow cathode structure having a surface characterized by a number of small openings, said cathode positioned within a first of said enclosures and electrically insulated therefrom, said cathode having an aperture through which an electron beam may pass,
 - a hollow control grid structure positioned within and substantially centrally of said cathode and electrically insulated therefrom, said grid having an aperture aligned with said cathode aperture,
 - means for supplying a high negative potential to said cathode relative to said housing,
 - means disposed in a wall of a second of said enclosures for introducing a low pressure gaseous medium into said second enclosure,
 - passage means disposed in a wall of said first enclosure for exhausting a portion of said gaseous medium within said first enclosure and thereby maintaining said gaseous medium within a predetermined low pressure range,
 - the first partitioning member separating said first and second enclosures having an aperture aligned with said cathode and grid apertures and sufficient in size for passage of an electron beam emitted by a plasma generated interior of said grid by interaction of said gaseous medium and high negative cathode potential and sufficient in size for passage of said gaseous medium from said second enclosure into said first enclosure,
 - means for operating said grid at an adjustable low potential relative to said cathode and thereby controlling the magnitude of current in said beam independently of the beam focus,
 - the second partitioning member separating said second and third enclosures having an aperture aligned with said cathode, grid and first partitioning member apertures and sufficient in size for passage of said electron beam and insufficient in size for appreciable passage of an undesired gas which may be generated in said third enclosure,
 - passage means disposed in a wall of said third enclosure for exhausting undesired gas generated by material irradiated by said electron beam within said third enclosure, and
 - said first partitioning member electrically insulated from the walls of said housing and provided with connections whereby an adjustable high negative potential may be impressed on said first partitioning member relative to said housing to provide electrostatic control of the beam focus on the material being irradiated in said third enclosure.

References Cited by the Examiner

UNITED STATES PATENTS

2,899,556	8/1959	Schopper et al.
3,009,050	11/1961	Steigerwald.

RICHARD M. WOOD, *Primary Examiner*.JOSEPH V. TRUHE, *Examiner*.