

Dec. 3, 1968

L. H. STAUFFER

3,414,702

NONTHERMIONIC ELECTRON BEAM APPARATUS

Filed May 28, 1965

Fig. 1.

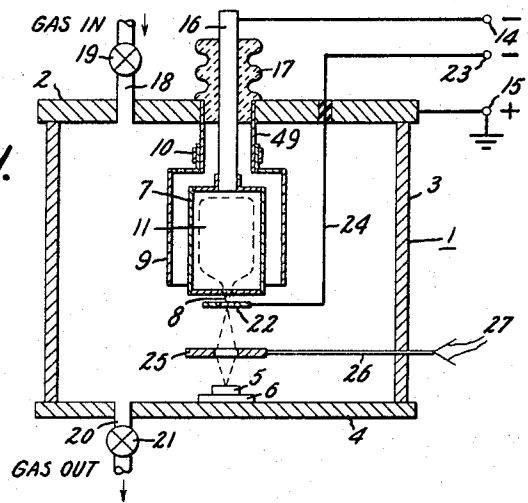
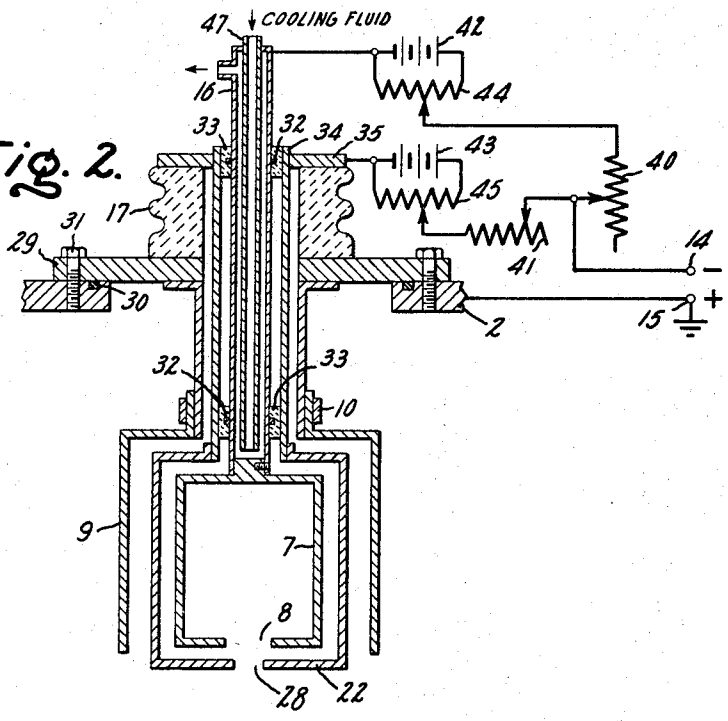


Fig. 2.



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

1

3,414,702

NONTHERMIONIC ELECTRON BEAM APPARATUS

Lynn H. Stauffer, Pattersonville, N.Y., assignor to General Electric Company, a corporation of New York
Filed May 28, 1965, Ser. No. 459,650
9 Claims. (Cl. 219-121)

ABSTRACT OF THE DISCLOSURE

A device for generating an electron beam by nonthermionic means includes a hollow imperforate cathode structure having an electron beam exit aperture, the cathode beam concentrically surrounded by an electrically conductive shield. A desired mode of operation, wherein the electron beam issues from the cathode aperture with convergence and subsequent divergence over a wide range of electron beam intensity, is obtained by positioning an electrode structure between the cathode structure and shield and concentric therewith. The electrode structure is of the same shape as the cathode, having an aperture aligned with the cathode aperture. Adjustment of a low electrical potential between cathode and electrode maintains the desired mode of operation.

My invention relates to improvements in electron beam irradiation apparatus of the gaseous or plasma type wherein the beam is generated nonthermionically, and in particular, to improvements in the electron gun assembly of the apparatus described in a copending patent application Ser. No. 289,357, filed June 20, 1963, now Patent No. 3,320,475, issued May 16, 1967, entitled, "Nonthermionic Electron Beam Apparatus," inventor Kenneth L. Boring, and assigned to the assignee of this application.

Apparatus for generating electron beams by utilizing a heat source which effects emission of electrons from a cathode thermionically are well known. Also well known are the gaseous discharge type of apparatus, such as the thyratron tube, which generate a diffuse type discharge in a gaseous medium by either thermionic or nonthermionic means. The diffuse discharge may be adapted to form a beam at a low efficiency by employing a suitable geometry of focusing apertures in combination with electromagnetic or electrostatic elements.

The above-identified patent application Ser. No. 289,357 describes a nonthermionically emitting electron gun assembly comprising a hollow cathode structure having imperforate side walls and a single exit aperture in an end wall through which a beam of electrons may be emitted and an electrically conductive shield substantially surrounding the cathode. The electron gun assembly is positioned within a housing and the interior thereof is subjected to a low pressure ionizable gas. A high negative cathode-to-housing potential is applied, and interaction of the gaseous medium and negative potential creates a body of plasma within the cathode cavity. The shield is maintained at the voltage of the housing (generally at ground potential). A control electrode structure may be positioned within, and is electrically insulated from, the cathode. Such control electrode varies the intensity of an electron beam issuing from the plasma by an automatic or manual control of a low potential between the control electrode and cathode. Although the control electrode provides a satisfactory control of the electron beam intensity (total electrical current within the electron beam), it has been found that the beam mode may change in the normal operating range of beam current from a desired beam mode having convergence and subsequent divergence to a parallel beam which cannot subsequently be conveniently focused by an external electromagnetic or electrostatic lens.

2

Therefore, one of the principal objects of my invention is to provide an improved apparatus for efficiently generating an electron beam by nonthermionic means.

Another object of my invention is to provide such apparatus for maintaining the electron beam in a desired mode over a large range of beam intensity.

A further object of my invention is to provide a new electron gun assembly for the electron beam apparatus.

A still further object of my invention is to provide a new electrode structure in the electron gun assembly.

Briefly stated, and in accordance with my invention, I provide what may be described as a double cathode structure substantially surrounded by an electrically conductive shield to form a unitary electron gun assembly (electron beam source) of my electron beam apparatus. The double cathode structure comprises an inner hollow cathode structure having imperforate side walls and a single aperture in an end wall thereof through which a beam of electrons may be emitted, and an outer hollow (electrode) structure, concentric with the inner, electrically insulated therefrom, and having a single aperture in an end wall thereof aligned with the aperture of the inner cathode. The shield surrounding the double cathode is concentric therewith, electrically insulated therefrom, and preferably maintained at ground potential. The electron beam is controlled by adjusting a relatively low potential between the inner cathode and outer electrode to vary the electric field within and around the inner cathode aperture with changing operating conditions and thereby maintain a desired beam mode (having a convergence and subsequent divergence) over a wide range of electron beam intensity.

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 character reference and wherein:

FIGURE 1 is an elevation view, partly in section, illustrating the general concept of a nonthermionically-emitting double cathode plasma electron beam source in accordance with my invention; and

FIGURE 2 is an enlarged detail view of a specific embodiment of such source and includes electrical circuitry for varying the potential between the inner cathode and outer electrode.

In the above-identified copending patent application, there is described a nonthermionically-emitting plasma electron beam source (hereinafter also referred to as an electron gun assembly) that comprises a hollow cathode structure substantially surrounded by an electrically conductive shield which is of the same general shape, concentric therewith, and electrically insulated therefrom. The hollow cathode structure has imperforate side walls and a single aperture in an end wall through which an electron beam may be emitted. A control electrode may be provided within the cathode cavity, electrically insulated therefrom, and having an aperture aligned with the cathode aperture. The electron gun assembly is positioned within an enclosed chamber or housing containing a low pressure ionizable gaseous medium (0 to approximately 200 micron, depending upon the particular gas), and a high negative cathode-to-housig potential (0 to approximately 30 kilovolts, and for some applications as high as 200 kilovolts), is applied, the surrounding shield being maintained at the voltage of the housing which, in general, is at ground potential. Variation of the gas pressure or cathode voltage controls the electron beam intensity. A controllable low potential (0 to approximately 200 volts) between the cathode and control electrode permits further control of

the electron beam intensity (total electron beam current) over a wide range of values of beam current. It has been found, however, that the desired mode of the electron beam often is lost at the higher beam intensities. The beam mode is herein defined as the characteristics of the emergent beam from the hollow cathode. In many applications, such as welding, the electron beam is required to be of high current density and focussed to a very small spot on the work piece, thus requiring that the emergent beam from the hollow cathode behave as though it came from a very small source to permit a suitable external lens (electromagnetic or electrostatic) to image the apparent source onto a small area on a work piece being irradiated by the beam. Thus, the desired beam mode must have convergence, i.e., a crossover point (within or external of the cathode), and subsequent divergence. It has been found that a parallel electron beam issuing from the hollow cathode cannot readily be focussed to a sufficiently small spot whereas a diverging beam is readily focussed by a simple external lens system.

The use of the plasma electron beam source described in the copending patent application has shown that the cathode aperture diameter, thickness of aperture end wall (aperture plate), shield-to-cathode separation, and the positive ion and electron space charge fields near the cathode aperture critically influence the beam divergence and its focusability. This apparently is due to the fact that the aperture and immediate vicinity thereof behave as an electrostatic lens. It obviously is impractical to vary these parameters to match different operating conditions such as, for example, when the gas pressure or voltage is varied to change the beam intensity. The purpose of my invention is to provide an electrostatic lens of adjustable strength to obtain the effect of varying the above-described parameters and thereby maintain the desired electron beam mode over a much wider range of beam intensity.

Before describing the improved plasma electron beam source which is the subject of my present invention, a brief summary of a theory for explaining the principle of electron beam formation and ejection from the hollow cathode will be provided, attention being directed to the copending patent application for additional explanation of the theory. It is well known that relatively high voltages must be applied to initiate electrical breakdown (discharge) across gaps which are short compared with the electron mean-free-path for ionization at the gas pressure existing in the gap. In such short gaps, multiplication of ions and electrons cannot take place because of the low probability of ionizing collisions at low gas pressures. Thus, discharges at low pressure tend to seek out long paths instead of short ones as is the case at higher pressures, and this phenomenon is employed to suppress radial electron emission from the hollow cathode (to the housing side walls) by closely fitting a concentric shield about the cathode. Any discharge which occurs across the gap (between the grounded shield and cathode) traverses the long path between the outer surface of the shield and the inner surface of the cathode or near the beam exit aperture. This circumstance confines positive ion bombardment largely to the inner cathode surface and to the outer surface of the cathode aperture plate. Proper spacing of the end of the shield with respect to the plane of the cathode aperture plate focusses most of the ions on the cathode aperture thereby generating secondary electrons within the cathode cavity. As a result of these phenomena an ionized body of plasma forms within the cathode cavity. The interior of a cathode 7 cavity in FIGURE 1 thus comprises a glowing body 11 of plasma or ionized gas being generated by an interaction of a low pressure gaseous medium and a high negative cathode to housing potential. This body of plasma is separated from the cathode walls by a less luminous sheath which is bounded by the cathode walls. A region of high voltage gradient (cathode dark space) surrounds the aperture end of the cathode externally thereof. The combined effect of the potential distribution inside the cathode

and cathode dark space allows the emergence of a stream of electrons from the plasma and initiation of electron beam formation. The shield 9 further aids in creating a suitable electric field distribution for beam mode operation, it being difficult to operate the cathode in such mode without the shield. Highly conducting gas outside the boundary of the cathode dark space acts as a virtual anode and the electrons in the beam gain most of their energy as they are accelerated in the space between cathode and dark space boundary. As the gas pressure is increased, the dark space shrinks and the electron beam current increases due to a corresponding increase of positive ion influx. Increasing the cathode voltage produces a nonlinear increase in beam current. Thus, beam current can be controlled by varying either cathode voltage or gas pressure.

For a desired level of beam intensity, the gas pressure and cathode voltage must each be within a critical range to obtain and maintain beam mode operation. The critical range within which beam mode operation exists is dependent primarily on the gaseous medium employed and to a lesser degree on the cathode voltage and geometry. A typical critical pressure range for beam mode operation is an argon medium and a cathode voltage of 20 kilovolts is 5 to 10 microns for a cylindrical cathode structure 3 inches (") long, 2 1/8" outside diameter, 2" inside diameter, aperture wall thickness of 0.05" and aperture diameter of 5/8". In the copending patent application the electron beam intensity is also controlled by positioning a control electrode or grid within the cathode cavity. A negative grid-cathode potential suppresses the flow of electrons from the cathode inner surface into the plasma, and a positive potential prevents the escape of slower electrons from the plasma to the cathode exit aperture. A relatively small grid-cathode potential has a significant effect on the beam current. Thus, a potential in the range of a 20 to 40 volts in many cases reduces the beam current by 50 percent.

The upper limit of current for each cathode is determined by the current magnitude which causes excessive heating of the aperture end by ion bombardment. It has been found that grid control can obtain this upper limit, but as such limit is approached, the mode of the electron beam changes from a desired convergent-subsequent divergent form which is preferred for welding and other applications requiring very small spot size and high current density, to a very nearly parallel form that is difficult to focus to a prescribed small spot size. Thus, in the shielded single-cathode electron beam source, with or without an internal grid, a larger cathode must be employed to maintain the desired beam mode when operating at higher current levels.

Referring now to FIGURE 1, there is shown the general concept of my improved plasma electron beam source. The electron gun assembly consists of a hollow cathode structure 7, preferably in the form of a cylinder although other shapes such as parallelepiped and spherical may be employed, having imperforate side walls and a single aperture 8 in the center of the bottom end wall thereof wherefrom the electron beam is emitted nonthermionically. The hollow cathode is constructed from an electrically conductive material which has a relatively high melting point to avoid melting at the temperature to which the cathode may be subjected at high beam intensity even though no heat source as such is utilized, and preferably must not emit significant amounts of gas at this temperature. A suitable embodiment of the cathode for high temperature applications is a construction wherein the side, bottom and top end walls are constructed from a sheet of molybdenum, although the top end wall may be constructed of stainless steel or copper. The cathode is conveniently assembled by welding or brazing of the end walls to the side walls to form a unitary structure.

An electrically conductive shield 9, having perforate or imperforate side walls surrounds cathode 7 in concentric relationship and is electrically insulated therefrom. Shield 9 has the same configuration as the cathode, and thus, is

preferably cylindrical, and has an open bottom end. Shield 9 may be made of sheet metal such as stainless steel and the spacing between cathode and shield is maintained sufficiently small to prevent a glow discharge in that space. The cathode-shield spacing is dependent on the cathode voltage, gas pressure and cathode-shield geometry. For the combination of the 3" long cathode hereinabove described, and an outer cathode to be described hereinafter, a shield having a 3" outside diameter and 2 7/8" inside diameter has proven satisfactory. The structure of shield 9 preferably includes a means for obtaining axial adjustment of shield 9 with respect to cathode 7. A preferable adjustment of shield 9 is a position whereby the bottom end thereof is slightly above the aperture end of the outer cathode, approximately 1/32" being satisfactory.

The electron gun assembly comprising cathode 7 and shield 9 is positioned within a housing designated as a whole by numeral 1, preferably of cylindrical shape, although other forms may also be employed. Housing 1 comprises a top end plate 2, hollow cylindrical wall 3 and bottom end plate 4, joined by well known methods. End plates 2 and 4 are constructed of an electrically conductive material such as metal, and wall 3 may also be constructed of such material, or, alternatively, may be made entirely or partially of a nonporous, transparent, heat resistant material to permit visual observation of the generated electron beam and its effect on an irradiated material or work piece 5 being processed by the beam. Work piece 5 is maintained in alignment with the electron beam by means of a movable support member 6, disposed on bottom end plate 4 and constructed of copper or other suitable good electrically conductive and heat conductive material. The anode of the electron beam apparatus primarily includes housing 1, shield 9 and support member 6. Suitable means (not shown) are provided to remove member 6 from housing 1 and thereby facilitate the insertion and withdrawal of material 5 being processed therein.

Cathode 7 is supported within housing 1 by a cathode stem 16 which is electrically insulated from top end plate 2 by means of high voltage insulating bushing 17. Stem 16 is an electrically conductive solid or hollow member which may be cylindrical in form and made of stainless steel. The solid form is employed when no internal passage is required for a cooling medium to remove heat being generated within cathode structure 7 by the plasma 11 within the cathode cavity. The cathode is connected to the stem by suitable means such as welding, brazing or a screw arrangement. Shield 9 is connected to top end plate 2 by suitable means such as a metallic tubular member 49 whereby shield 9 is operable at the same potential as top end plate 2 relative to the cathode. A conventional clamping means 10 permits axial adjustment of shield 9 with respect to cathode 7.

The output of a high voltage direct current power supply (not shown) providing a controlled output voltage is connected to terminals 14 and 15, housing 1 being maintained at ground potential, as illustrated, for many applications. The power supply output voltage is adjustable from zero to approximately 30 kilovolts, and for some applications may be as high as 200 kilovolts. The power rating of the supply is dependent upon the particular application and may be in the order of 30 kilowatts for applications such as welding, brazing, melting and annealing of materials such as steel, aluminum, copper and refractory metals such as niobium and molybdenum. The negative terminal 14 of the power supply is connected to cathode stem 16 whereby the cathode is operable at a relatively high negative potential with respect to the anode.

A suitable gas such as argon, helium, nitrogen or hydrogen is introduced into the interior of housing 1 through passage 18 which may pass through any wall of housing 1, and for illustrative purposes is shown as passing through top end plate 2. Passage 18 is connected to a gas supply (not shown) through throttle valve 19 which regulates the rate of gas flow into housing 1. A second

passage 20 is preferably located in a wall of housing 1 remote from passage 18 and is illustrated as passing through bottom end plate 4. An exhaust pumping device (not shown) is connected to passage 20 through regulating valve 21 and aids in maintaining a desired gas pressure within housing 1. Thus, possible contamination of the cathode by undesired gases generated by the irradiated material 5 is largely prevented with such an exhaust system.

The particular improvement in the plasma electron beam source in accordance with my present invention is the provision of the electrostatic lens of adjustable strength hereinabove mentioned to vary the electric field within and around the cathode aperture 8 and thereby maintain the desired electron beam mode over a much wider range of beam intensity. The electrostatic lens consists of the aperture end of the cathode and an auxiliary aperture plate or electrode 22 which is positioned external of and in close proximity to the cathode aperture 8, the two apertures being aligned. It is recognized that shield 9 and the aperture end of the cathode exert an additional electrostatic lens effect. Auxiliary aperture plate 22 may be supported within housing 1 in any convenient manner and obtains an electrostatic lens effect having an adjustable strength due to an adjustable auxiliary aperture plate-cathode potential which may be varied by external means. For purposes of simplicity, auxiliary aperture plate 22 is illustrated in FIGURE 1 as being connected to a second negative terminal 23 of the power supply by means of electrical conductor 24 which also functions to support auxiliary plate 22 in its position closely adjacent cathode aperture 8. Conductor 24 is suitably electrically insulated in its passage through top end plate 2. As a result, the electrostatic lens effect of aperture 8 which by itself does not sufficiently influence the electron beam divergence and focusability especially at higher levels of beam intensity is suitably modified by the auxiliary aperture plate 22, hereinafter described as auxiliary electrode 22 having adjustable potential. The combined effect of the variable electrostatic lens effect of aperture 8 and the controllably adjustable effect of electrode 22, upon correct adjustment of the auxiliary electrode-cathode potential, maintains the electron beam in the desired beam mode having beam convergence (a crossover point) and subsequent beam divergence over a wider range of beam current than obtained without such auxiliary electrode.

An external beam focusing lens 25 of the electrostatic or electromagnet type is positioned approximately midway between the bottom of cathode 7 and work piece 5. Auxiliary electrode 22 is, in general, spaced from the cathode within the distance of one cathode diameter, external focusing lens 25 is positioned at approximately 5 to 10 diameters from the cathode. Focusing lens 25 is supported within chamber 1 by means of a tube 26 through which pass suitable electrical conductors 27 for supplying electric power to the focusing lens. Thus, it may be seen in FIGURE 1 that the coaction of aperture 8 and auxiliary electrode 22 obtains a desired electron beam divergence that is readily focussed to a very small spot on work piece 5 by means of focusing lens 25.

Referring now to FIGURE 2, there is shown a specific embodiment of the improved plasma electron beam source constructed in accordance with my invention. The auxiliary aperture plate or electrode 22 illustrated in FIGURE 1 is embodied as an outer hollow electrode structure disposed between inner cathode 7 and shield 9 in concentric relationship and spaced and electrically insulated therefrom. Outer electrode 22 is of the same shape as cathode 7, the side walls of electrode 22 also being of the same shape as shield 9. Electrode 22 has an aperture 28 which need not be the same size as aperture 8 but is aligned therewith. The cylindrical side walls of electrode 22 (in the case of a cylindrical cathode 7) may be perforate or imperforate, an imperforate structure being preferred for purposes of structural rigidity. The sidewalls

of electrode 22 need not be of imperforate construction as in the case of cathode 7 since positive ion bombardment is confined to the inner surface of cathode 7 and the outer surface of the aperture plate portion of electrode 22. The active element of electrode 22 is the exit aperture end wall (aperture plate portion) thereof, the cylindrical side wall portion and other parts of electrode 22 merely being the means for supporting the aperture wall in position and for supplying voltage thereto. This aperture end wall of electrode 22 is of imperforate construction except for centrally located aperture 28. For the particular 3" long, 2½" outside diameter cathode 7, and 3" outside diameter shield hereinabove described, an outer electrode having the following dimensions has proven satisfactory: 4¾" long, 2½" outside diameter, 2¾" inside diameter, aperture wall thickness of 0.05" and aperture diameter of ⅞".

Although the plasma electron beam source may be positioned within the irradiation chamber comprising housing 1 by being connected through top end plate 2 as illustrated in FIGURE 1, it is more common to assemble the plasma electron beam source as a unitary structure with a flange 29 as illustrated in FIGURE 2. The use of the flange construction permits a more simple method for insertion and withdrawal of the source from housing 1 as opposed to the case in FIGURE 1 wherein the entire top end plate 2 must be removed. Flange 29 may be connected to top end plate 2 by any well known gas-tight sealing technique such as an O-ring gasket 30. A bolt arrangement 31 is preferably employed to maintain alignment of the electron beam source within top plate 2 and to assure electrical continuity between plate 2 and flange 29. A variable spacing adjustment between the aperture ends of inner cathode 7 and outer electrode 22 can be provided by incorporating a sliding vacuum seal such as an O-ring 32 in the electrical insulators 33 which support the inner cathode stem 16.

Cathode 7 and auxiliary outer electrode 22 are each illustrated as supported from their respective stems 16 and 34 by set screw arrangements for ease of removal therefrom, it being understood that other connections including permanent (welded or brazed) connections may also be employed. Inner cathode stem 16 may be solid or hollow (as shown), dependent upon whether a cathode cooling fluid such as water or gas is to be circulated therein. A coaxial cooling circuit 47 is illustrated in FIGURE 2. Outer electrode stem 34 of necessity must be hollow to retain a preferred concentric and spaced apart relationship with inner stem 16. A cooling medium may also be circulated through stem 34 for cooling outer electrode 22, if desired. In the general case, inner cathode 7 is cooled and outer electrode 22 is not, as shown, since only the inner surface of cathode 7 and outer surface of the aperture plate portion of electrode 22 are subject to positive ion bombardment. An electrically conductive collar 35 is connected to outer electrode stem 34 and to high voltage insulating bushing 17, and provides support for the double stem arrangement 16, 34 is spaced apart relationship from insulator 17 to maintain the long discharge path over the surfaces thereof.

Two convenient methods for varying the potential between inner cathode 7 and outer electrode 22 are illustrated in FIGURE 2. Since both the cathode and electrode draw electron current, although the outer electrode current is much smaller than the inner cathode current, a resistance in series with either cathode or electrode will increase its potential with respect to ground. Thus, by connecting adjustable resistors in series with the cathode and auxiliary electrode, a range of potential differences between the inner cathode and outer electrode is obtained to control the electric field in the immediate vicinity of aperture 8. This first method of varying the inner cathode-outer electrode potential is accomplished by variable resistances such as rheostats 40 and 41 having a juncture thereof connected to negative terminal 14 of the high

voltage power supply. Adjustment of resistances 40 and 41 obtains a variation in potential of either polarity between the cathode and auxiliary electrode over a range of approximately 0 to 1,000 volts. It should be understood that this potential could also be provided by an additional direct current power source. The use of variable resistances 40, 41 also provides self-regulation or automatic stabilization of the electron beam current since a change in beam current due to moderate changes in the high voltage supplied to terminals 14 and 15 or changes in the pressure of the gaseous medium in housing 1 is automatically corrected by the changes in voltage drops across resistances 40, 41 produced by the changing currents flowing therethrough. The net change in these voltage drops is in such direction as to restore electron beam current to its desired value.

A second method for varying the potential between the inner cathode and outer electrode is the use of a direct current power source connected in series circuit relationship with each of these elements. Thus, as illustrated in FIGURE 2, direct current sources 42 and 43 are connected in series with the inner cathode and outer electrode, respectively, each battery being shunted by a suitable potential divider. A juncture of the two shunted battery circuits is connected to negative terminal 14. The voltage rating of batteries 42, 43 and the position of the movable arms of potentiometers 44 and 45 connected respectively thereacross determines the polarity and magnitude of the potential between the cathode and auxiliary electrode. It is obvious that only one of the two methods for varying the cathode-auxiliary electrode potential is employed at one time, the first or series resistance 40, 41 method being preferred since no additional voltage sources are required and automatic stabilization of electron beam current is obtained.

It has been found that operating the inner cathode positive with respect to the outer electrode is more effective than the reverse polarity in maintaining the desired beam mode of operation wherein there is a beam convergence (actual beam crossover point) in the immediate vicinity of the cathode aperture and subsequent beam divergence. An example of the results obtained with the electron beam source having the heretofore described dimensions is as follows: Operation in a nitrogen environment at 5.2 micron pressure, and 10 kilovolts cathode-housing potential (0.15 ampere beam current) is in the desired beam mode for either a single or double cathode. However, increasing the cathode-housing potential to 20 kilovolts (at 4.5 micron pressure and 0.19 ampere beam current) results in a change in the beam mode for the single cathode to a more nearly parallel beam which cannot be focussed to a desirably small spot size by focusing lens 25, the spot size diameter being approximately 0.100 inch. In the case of the double cathode at 20 kilovolts potential, the desired beam mode is maintained, the beam being focussed to a spot size diameter of approximately 0.029 inch with a cathode-auxiliary electrode potential of +500 volts.

From the foregoing description, it can be appreciated that my invention attains the objectives set forth and makes available an improved electron beam source for generating electron beams by nonthermionic means. The improved electron beam source is an electron gun assembly which includes a single-aperture hollow cathode structure that is operable at a relatively high voltage, and a shield substantially surrounding the cathode, the improvement comprising an aperture plate positioned external of an aperture end of the cathode and adapted to have a potential applied between the cathode and aperture plate. For structural rigidity reasons to form a unitary structure, the aperture plate is in the form of a second single-aperture hollow electrode structure positioned between the cathode and shield, concentric therewith and electrically insulated therefrom. Adjustment of a positive inner cathode-to-outer electrode potential results in a modifi-

cation of the electric field in the immediate vicinity of the cathode aperture and thereby maintains the electron beam in a desired mode of convergence and subsequent divergence over a wider range of beam current than is possible with merely a cathode-shield assembly. Finally, the electron beam source herein described is also capable of controlling the magnitude of beam current by variation of the cathode-electrode potential, although to a lesser degree than in the case of the internal grid controlled cathode hereinbefore mentioned.

Having described a general and specific embodiment of an improved electron gun assembly which is utilized in an apparatus for generating an electron beam, it is believed obvious that modification and variation of my invention is possible in the light of the above teachings. Thus, various configurations of the cathode, outer electrode and shield may be employed, the configurations of the three elements in each particular application preferably being the same. Further, the particular structure of the insulators and cathode and electrode stems for supporting the electron gun assembly within the housing may have many forms since the particular description and illustration in FIGURE 2 is not deemed to be a limitation thereof. In particular, for ease of assembly and disassembly of the electron beam source, the inner cathode and outer auxiliary electrode, and for that matter, also the shield can be open-ended structures such as cylinders which can be attached to top ends thereof by suitable means. Finally, it is to be understood that the housing itself, or a recess therein, as described in the copending patent application, may provide the function of shield 9, in which case shield 9, as such, is omitted and a part of the housing is then the shield. It is, therefore, to be understood that changes may be made in the particular embodiment 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 gun assembly for use in an electron beam irradiation apparatus which comprises an enclosure containing a relatively low pressure ionizable gaseous medium, a hollow cathode structure having a beam exit aperture, operating circuit means effective for operating said cathode and a potential sufficiently negative relative to an anode in the operating circuit to initiate and maintain a plasma within the cathode structure by the interaction of the gaseous medium and negative cathode-to-anode potential thereby to effect a nonthermionic electron beam mode of operation of said cathode wherein an electron beam issues from the plasma through said aperture, said cathode structure comprising

a hollow, electrically conductive cathode member having imperforate side walls and a single aperture in an end wall thereof,

an electrically conductive shield surrounding said cathode in concentric relationship and electrically insulated therefrom and comprising part of the anode, and

means external of said cathode and internal of said shield and electrically insulated therefrom and positioned in concentric relationship therewith for controlling an electric field generated in the immediate vicinity of the cathode aperture upon application of the sufficiently negative cathode-to-anode electric potential to thereby maintain the electron beam issuing from the cathode aperture in a desired mode of convergence and subsequent divergence over a relatively wide range of electron beam intensity.

2. An electron gun assembly for use in an electron beam irradiation apparatus which comprises an enclosure containing a relatively low pressure ionizable gaseous medium, a hollow cathode structure having a beam exit aperture, operating circuit means effective for operating said cathode and a potential sufficiently negative relative

to an anode in the operating circuit to initiate and maintain a plasma within the cathode structure by the interaction of the gaseous medium and negative cathode-to-anode potential thereby to effect a nonthermionic electron beam mode of operation of said cathode wherein an electron beam issues from the plasma through said aperture, said cathode structure comprising

a first hollow, electrically conductive cathode member having imperforate side walls and a single aperture to an end wall thereof,

an electrically conductive shield surrounding said first cathode member and electrically insulated therefrom, and

a second hollow electrically conductive member positioned between said cathode and said shield and electrically insulated therefrom, said second member having a single aperture in an end wall thereof and in alignment with the cathode aperture for controlling an electric field generated in the immediate vicinity of the cathode aperture upon application of the sufficiently negative first cathode-to-anode electric potential to thereby maintain the electron beam issuing from the cathode aperture in a desired mode of convergence and subsequent divergence while operating over a wide range of electron beam intensity.

3. An electron beam source comprising

a first hollow, electrically conductive cathode member having imperforate side walls and a single aperture in an end wall thereof,

a second hollow, electrically conductive electrode member surrounding said first cathode in concentric relationship and spaced in close proximity thereto and electrically insulated therefrom, said second electrode having a single aperture in an end wall thereof and in alignment with the first cathode aperture,

an electrically conductive shield substantially surrounding said second electrode in concentric relationship and spaced in close proximity thereto and electrically insulated therefrom, said shield having side walls of the same shape as side walls of said first cathode and second electrode,

means for supporting said first cathode and second electrode and shield in fixed spaced apart relationship to form a unitary structure at least partially mounted within an enclosed chamber, and

electric circuit means external of the chamber and connected to selected electrically conductive parts of said supporting means for supplying a variable electric potential between said first cathode and second electrode to control an electric field generated in the immediate vicinity of the first cathode aperture upon application of a relatively high negative first cathode-to-shield electric potential while maintaining the electron beam source in the interior of the chamber at a relatively low pressure of ionizable gaseous medium to thereby maintain an electron beam issuing from the first cathode aperture in a desired mode of convergence and subsequent divergence while operating over a wide range of electron beam intensity.

4. The electron beam source set forth in claim 3 wherein said electric circuit means comprises a first and second adjustable resistance respectively connected in series circuit relationship with said first cathode and said second electrode, said two resistances having a juncture connected to a negative terminal of a power source which supplies the negative first cathode-to-shield potential.

5. The electron beam source set forth in claim 3 wherein said electric circuit means comprises a first and second direct current power source shunted by a potential divider respectively connected in series circuit relationship with said first cathode and said second electrode and having a juncture connected to a negative terminal of a power source which supplies the negative first cathode-to-shield potential.

6. An electron beam irradiation apparatus comprising a chamber,
 a hollow, electrically conductive cathode member positioned within said chamber and having imperforate side walls and a single aperture in an end wall thereof, 5
 an electrically conductive shield positioned within said chamber and substantially surrounding said cathode in concentric relationship and electrically insulated therefrom, said shield having side walls of the same shape as the side walls of the cathode, 10
 means for supplying a relatively high negative cathode-to-chamber electric potential,
 means for supplying a relatively low pressure ionizable gaseous medium to the interior of said chamber whereby interaction of the gaseous medium and the negative electric potential produces a plasma within the cathode cavity, and
 means positioned within said chamber external of the cathode and internal of said shield and concentric therewith for controlling an electric field in the immediate vicinity of the cathode aperture to thereby maintain an electron beam which issues from the plasma and passes through the cathode aperture in a desired mode of convergence and subsequent divergence over a wide range of electron beam intensity. 25

7. The apparatus set forth in claim 6 and further comprising an electron beam focusing lens positioned within said chamber and spaced at a relatively large distance from the cathode aperture for focusing the electron beam on a workpiece being processed thereby. 30

8. An electron beam irradiation apparatus comprising a chamber,
 a first hollow, electrically conductive cathode member positioned within said chamber and having imperforate side walls and a single aperture in an end wall thereof, 35
 a second hollow, electrically conductive electrode member surrounding said first cathode in concentric relationship and electrically insulated therefrom, said second electrode having a single aperture in an end wall thereof and in alignment with the first cathode aperture, 40
 an electrically conductive shield substantially surrounding said second electrode in concentric relationship and electrically insulated therefrom, 45
 means for supplying a relatively high negative first cathode-to-chamber electric potential,
 means for supplying a relatively low pressure ionizable gaseous medium to the interior of said chamber whereby interaction of the gaseous medium and the negative electric potential produces a plasma within the first cathode cavity, and
 means for supplying a relatively low electric potential between said first cathode and second electrode to control an electric field in the immediate vicinity of the first cathode aperture and thereby maintain an electron beam which issues from the plasma and passes through the first cathode and second electrode apertures in a desired mode of convergence and 60

subsequent divergence over a wide range of electron beam intensity.

9. An electron beam welding apparatus comprising a chamber,
 a first hollow, electrically conductive cathode structure supported within said chamber in a fixed position and having imperforate side walls and a single aperture in an end wall thereof,
 a second hollow, electrically conductive electrode structure supported within said chamber in a fixed position in close proximity to the first cathode and surrounding the first cathode in concentric relationship thereto and electrically insulated therefrom, said second electrode having a single aperture in an end wall thereof and in alignment with the first cathode aperture, said second electrode having side walls of the same shape as the side walls of said first cathode, an electrically conductive shield supported within said chamber in a fixed position in close proximity to said second electrode and substantially surrounding said second electrode in concentric relationship thereto and electrically insulated therefrom, said shield having side walls of the same shape as the side walls of said first cathode, said shield being operatively connected to said chamber,
 means for supplying a relatively high negative first cathode-to-chamber electric potential,
 means for supplying a relatively low pressure ionizable gaseous medium to the interior of said chamber whereby interaction of the gaseous medium and the negative electric potential produces a plasma within the first cathode cavity, and
 electric circuit means for supplying a relatively low variable electric potential between said first cathode and second electrode to control an electric field in the immediate vicinity of the first cathode aperture and thereby maintain an electron beam in a desired mode of convergence and subsequent divergence over a wide range of electron beam intensity wherein the electron beam issues from the plasma and passes through the first cathode and second electrode apertures to a workpiece being welded.

References Cited

UNITED STATES PATENTS

2,969,475	1/1961	Berghaus	313—231
3,210,518	10/1965	Morley et al.	313—339
3,218,431	11/1965	Stauffer	219—121
3,223,885	12/1965	Stauffer	315—111
3,243,570	3/1966	Boring	219—121
3,262,013	7/1966	Allen	315—326
3,308,325	3/1967	Gaydou	313—207
3,312,858	4/1967	Dietrich	219—121
3,320,475	5/1967	Boring	219—121
3,327,090	6/1967	Greene	219—121

RICHARD M. WOOD, *Primary Examiner.*

W. D. BROOKS, *Assistant Examiner.*