

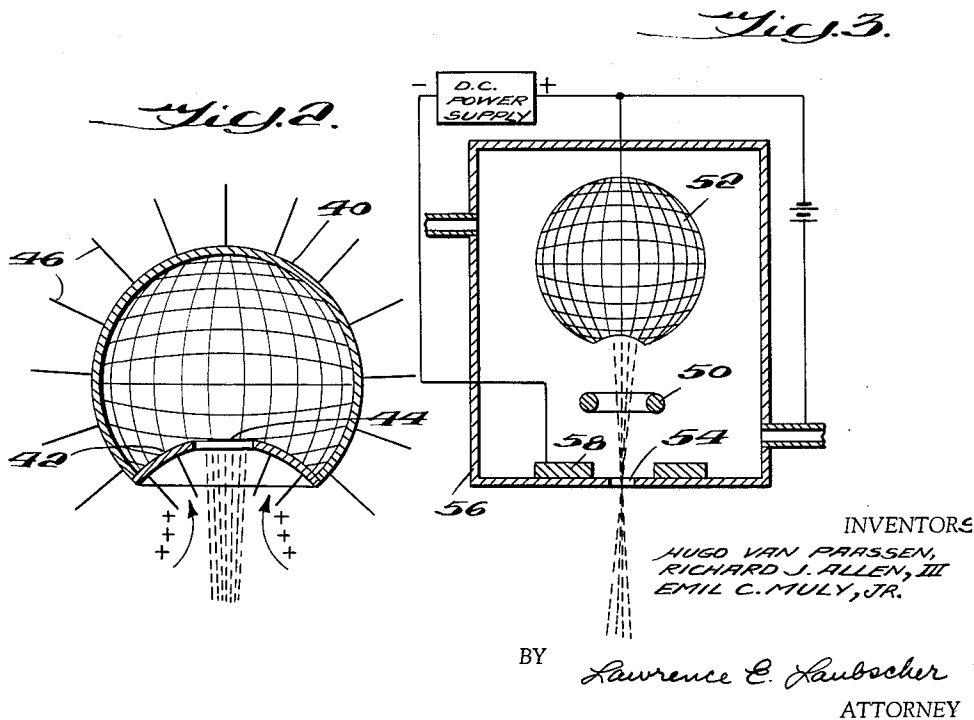
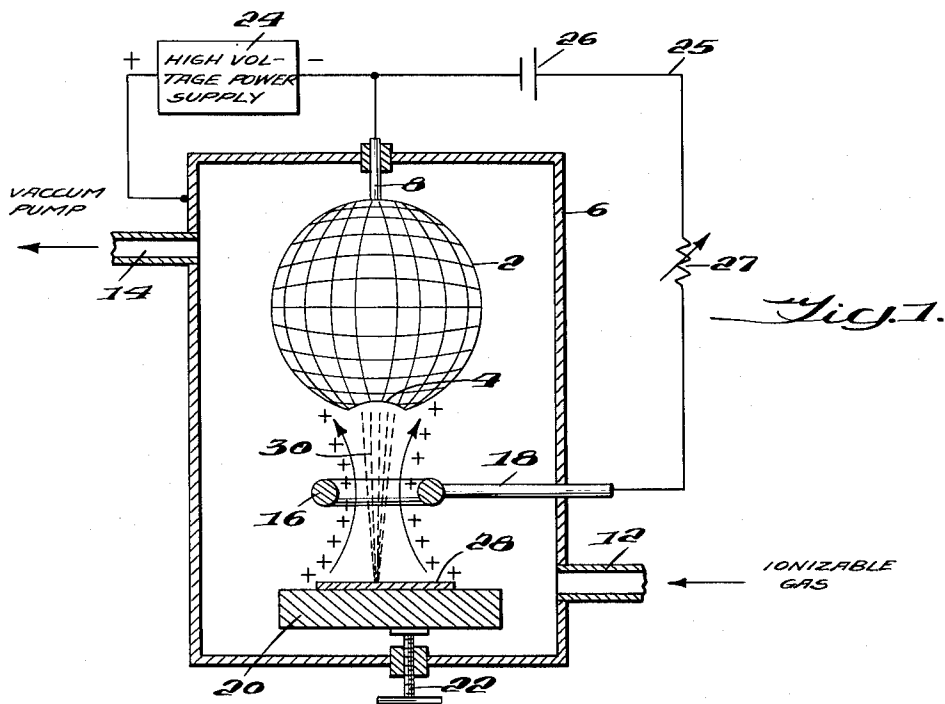
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R. J. ALLEN III, ETAL

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PERFORATED HOLLOW CATHODE DISCHARGE DEVICE

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PERFORATED HOLLOW CATHODE DISCHARGE DEVICE

Richard J. Allen III, Hugo L. L. Van Paassen, and Emil C. Muly, Jr., Baltimore, Md., assignors to Martin-Marietta Corporation, Baltimore, Md., a corporation of Maryland

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This invention relates generally to an electronic discharge device for producing an intense, concentrated beam of electrons by means of a perforated hollow cathode.

In the copending application of Hugo Van Paassen and Richard J. Allen, Serial Number 170,697, filed February 2, 1962, and entitled "Perforated Hollow Cathode Discharge Device," a discharge device is disclosed that is operable to produce alternately "narrow beam" and conventional "diffused glow" types of electrical discharge. In the previously disclosed apparatus, use is made of a hollow cathode having a generally spherical cavity. At least a portion of the hollow cathode wall is perforated and is provided with an aperture through which electrons concentrated within the cathode cavity are discharged. When the perforated hollow cathode is provided with an appropriate cathode to anode potential and is arranged in an ionizable gaseous medium having a low subatmospheric pressure, an intense narrow beam of electrons is generated which heretofore was unobtainable with conventional hollow cathode discharge devices. As disclosed in the aforementioned application, the generated electron beam has proved to be so unusually intense for given electrical input power levels that protective means are often required to prevent shattering or damage to the walls of the chamber containing the discharge elements. In one laboratory test, input power on the order of 100 watts was observed to generate an electron beam of such intensity as to produce shattering of glass plates and piercing of holes in ceramic crucibles positioned in the chamber. Consequently, among other uses, the prior device has been found to have utility as an electron beam welder for welding various metals.

The intensity of the electron beam generated by the previously disclosed device is limited, however, by the fact that when certain "transition" input power and cathode potential levels are exceeded, the perforated hollow cathode automatically switches over from the "narrow beam" mode of operation to the conventional "diffused glow" mode. Accordingly, an object of the present invention is to provide an electronic discharge device of the perforated hollow cathode type which will maintain the narrow beam mode of discharge for levels of input power and cathode potential that greatly exceed the "narrow beam" to "diffused glow" transition values previously achieved with the prior discharge device and thereby produce an electron beam of extremely high intensity and concentration.

In perforated hollow cathode discharge devices, consideration must be given to the magnitude and direction of the flow of ions produced by and in conjunction with the electron beam. On the one hand, the narrow beam discharge mode of operation of the perforated hollow cathode is sustained by the flow of ions or neutral gas molecules into the cathode cavity via the perforations in the cathode body wall, and consequently this ion flow must not be interrupted. On the other hand, the flow of ions into the cathode cavity via the aperture should be avoided as much as possible, since the flow of a large number of ions through the aperture in a direction opposed to the direction of electron beam gen-

eration establishes a conductive path which causes switching over of the discharge to the diffused glow mode. Thus, a more specific object of the invention is to provide means for dispersing the ions flowing toward the cathode aperture radially outwardly upon perforated portions of the cathode body remote from the aperture, whereby the narrow beam discharge mode may be sustained for input power levels greatly in excess of the transition levels of the discharge device disclosed in the aforementioned copending application.

A more specific object of the invention is to provide a perforated hollow cathode discharge device having auxiliary electrode means operable simultaneously to focus the electron beam and to de-focus the ion stream to cause deflection of the ions away from the cathode aperture. In one embodiment of the invention, the ion dispersing means comprises one or more members spaced from the cathode body in the direction of electron beam generation and containing through openings receiving the generated electron beam. The ion dispersing means may comprise an annular auxiliary electrode having a potential which varies slightly (less than approximately 20% and generally in the positive sense) from cathode potential to produce a focussing effect on the electrons flowing therethrough in one direction and a de-focussing effect on the ions flowing therethrough in the opposite direction. The ions of the de-focussed ion stream are dispersed on perforated areas of the cathode as remote as possible from the aperture so that the narrow beam mode may be maintained for extremely high electrical power input energy.

A further object of the invention is to provide a perforated hollow cathode body having such a configuration as to produce an electrostatic field which will disperse a stream of ions directed toward the cathode aperture upon perforated portions of the cathode remote from the aperture. According to another embodiment of the invention, the ion dispersion in a direction radially outwardly from the cathode aperture is achieved by an electrostatic field having a predetermined configuration dependent upon the specific configuration of the cathode body surface. For example, by providing a perforated portion of the cathode body containing the aperture with a concave recess, an electrostatic field is developed of such configuration as to disperse the ions radially outwardly from the aperture. This embodiment offers the advantage that the need for auxiliary electrodes and attendant means for supplying appropriate biasing potential thereto is obviated.

Other objects and advantages of the invention will become apparent from a study of the following specification when considered in conjunction with the accompanying drawing in which:

FIG. 1 is a schematic diagram of one embodiment of the invention using an auxiliary electrode for dispersing the stream of ions flowing toward the aperture;

FIG. 2 is a sectional view of another embodiment of the invention wherein the specific configuration of the perforated hollow cathode body results in dispersion of the ions radially outwardly from the cathode aperture; and

FIG. 3 illustrates an embodiment in which the electron beam is emitted from the ionization chamber.

Referring to FIG. 1, the perforated hollow cathode body 2 provided with aperture 4 is mounted within anode chamber 6 by means of insulated terminal 8. As disclosed in the aforementioned Van Paassen et al. application, the cathode body is formed of a mesh screen (consisting of copper, aluminum, stainless steel, or other suitable metal or alloy) and is provided with a generally spherical cavity. The anode chamber is supplied with an ionizable gas, such as helium, via inlet 12 and is main-

tained at a low subatmospheric pressure by means of a vacuum pump connected with chamber outlet 14.

According to the present invention, annular electrode 16 is mounted within the anode chamber opposite cathode aperture 4 by means of insulated terminal 18. Workpiece support 20, adjustably movable within the anode chamber by adjusting means 22, is arranged on the opposite side of electrode 16 from aperture 4. High voltage D.C. power supply 24 causes anode 6 to have a high positive potential relative to cathode 2, and branch circuit 25, including battery 26 and variable resistance 27, causes auxiliary electrode 16 to have a small positive potential relative to the cathode.

Operation

Assume that it is desired to weld a workpiece 28 consisting of a material that is normally difficult to weld, for example, titanium, tungsten, molybdenum, or the like. Assume further that the anode chamber contains helium gas at a low subatmospheric pressure (in the microns of mercury pressure range) and that the anode to cathode and auxiliary electrode to cathode potentials are such as to cause the discharge device to operate initially in the "narrow beam" mode. An intense beam of electrons 30 originating within the cathode is emitted through aperture 4 and extends through annular electrode 16 toward workpiece 28. Owing to the intensity of the electron beam, gas molecules are ionized along the path of the beam and the resulting ions are attracted toward the cathode. These ions define an ion stream flowing in a direction opposite to, and in a path generally concentric with, the electron beam. As shown diagrammatically by the arrows and plus symbols in FIG. 1, the annular electrode 16 results in deflection of the ion stream to cause the ions to be dispersed radially outwardly upon perforated portions of the cathode body remote from aperture 4. Some of the ions strike the cathode body and produce electrons by secondary emission, and other ions entering the cavity via the perforations produce electrons by collisions with neutral gas molecules. Further electrons are produced by cathode emission and photo ionization. These electrons are continuously collected within the center of the spherical cavity and effect an electron discharge through the aperture in the form of a narrow beam.

Laboratory testing has indicated that the maximum power level for operating a 2" spherical perforated hollow cathode body in the narrow beam mode without the use of an auxiliary electrode 16 (in accordance with the teachings of the aforementioned prior application) under certain operating conditions was 77 watts (3500 volts and 22 ma.). When, in accordance with the present invention, the same cathode body was used in combination with an auxiliary electrode 16 under identical operating conditions, the narrow beam mode of operation was maintained at a power level of 2600 watts (13,000 volts and 200 ma.). Thus it is apparent that the combination of the auxiliary electrode with the perforated hollow cathode achieves the narrow beam mode of operation for materially greater power levels to thereby produce an extremely intense electron beam. The beam is focussed by the auxiliary anode to achieve high electron density, and when the support 20 is adjusted to position the workpiece 28 at the focal point of the beam, the beam is of sufficient intensity to effect welding of metals which heretofore could be welded only by conventional, expensive high-power high-vacuum electron beam welding guns.

The present invention offers many advantages over conventional electron beam welding equipment. For one thing, the improved perforated hollow cathode discharge device makes use of components that are considerably less expensive than the corresponding components of conventional high vacuum electron beam welders. The electron emission means comprises an inexpensive perforated hollow cathode which requires no machining or complex manufacturing techniques as distinguished from the ex-

pensive delicate-filament emitter means of the known beam welders. The instant invention avoids the use of expensive-focussing coils and attendant power supplies conventional in the known beam welders, and consequently the number of high voltage feed-through terminals is reduced from four or more to two (one for the cathode and one for the auxiliary electrode). Since conventional beam welders require a considerably higher (on the order of 100 to 10,000 times higher) vacuum than is required by the present invention for successful generation of the beam, the degree of sealing of the welding chamber, the efficiency of the chamber-evacuating suction pump, and the time required for obtaining suitable beam-generating pressure conditions are considerably lower for the improved perforated cathode discharge device. Small variations in pressure (on the order of 10 microns or more) will not seriously affect the narrow beam discharge mode. On the other hand, a pressure rise of as much as 0.05 to 0.10 micron causes arcing in a conventional high-vacuum electron gun and necessitates shut down. The potential of the auxiliary electrode relative to the cathode is not critical since tests indicate that an improved result over the previously disclosed perforated cathode discharge device is obtained when the auxiliary electrode is at cathode potential. However, the potential of the auxiliary electrode relative to the cathode should be less than approximately 20% of cathode to anode potential. While the potential of the auxiliary electrode may be negative relative to the cathode, in general the auxiliary electrode is caused to be positive relative to the cathode. In high vacuum electron beam guns, beam focussing requirements dictate that the D.C. supply be of high quality and reasonably well filtered. In the perforated hollow cathode device, on the other hand, the quality of the D.C. supply is not critical.

According to the present invention, the focal length of the electron beam may be varied in accordance with variations in the potential of the auxiliary electrode (for example, by variation of the resistance of variable resistor 27). Thus the position of the focal point of the beam may be controlled without adjusting either the gas pressure or cathode voltage. Furthermore, in one alternate application of the invention wherein the narrow electron beam operates as an antenna for the generation and/or reception of radio frequency waves, the potential of the auxiliary electrode may be varied to effect modulation of the beam. Since the generated beam may be produced in an ionizable plasma with relatively low power requirements, the improved perforated hollow cathode device is particularly suitable for use in outer space communication systems. While the auxiliary electrode has been illustrated as being annular, it is contemplated that other types of auxiliary electrodes will produce suitable improved narrow beam operation. In certain applications, a plurality of auxiliary electrodes of the same or diverse types may be used as desired.

Referring now to the embodiment of FIG. 2, the perforated hollow cathode body 40 is provided with a perforated concave recessed portion 42 containing aperture 44. Owing to the concavity, the electrostatic field 46 produced by the negative cathode potential has a configuration adjacent aperture 44 which tends to radially outwardly deflect the ion stream upon perforated portions of the cathode remote from the aperture. In this manner, the flow of return ions into the cavity via the aperture is reduced, and consequently electron beams of higher density are generated than with cathode bodies provided with convex or planar portions containing the aperture. The cathode body of FIG. 2 may or may not be used with the auxiliary electrode means of FIG. 1 depending on the desired intensity of the beam. If the cathode body of FIG. 2 is used in combination with an auxiliary electrode, beam intensities greater than those of the embodiment of FIG. 1 or the embodiment of the

prior Van Paassen et al. application are produced for the same input power levels and the same operating conditions.

Since the perforated hollow cathode device is operable in the narrow beam mode with a pressure that is relatively high with respect to the operating pressures of high vacuum electron guns, it is possible to direct the beam through an opening in the ionization chamber as shown in FIG. 3. The gaseous medium external of the chamber may be at atmospheric pressure. If desired, the beam may be directed through an intermediate pressure chamber arranged adjacent the chamber opening and having a pressure (determined by auxiliary suction pump means, for example) differing from atmospheric pressure and the ionization chamber pressure. The auxiliary anode 50 serves to focus the electron beam generated by cathode 52 at a focal point lying within opening 54 in chamber housing 56. This embodiment has utility both in welding as well as in antenna application of the invention. It should be noted that when the beam is directed into an ionizable plasma external of the housing, both the opening 54 and the auxiliary electrode 50 serve to disperse the ions of the return ion stream upon perforated portions of the cathode remote from the aperture.

While the cathode bodies are generally formed of wire screening having a uniform mesh, it is apparent that the perforations of the cathode portions upon which the ions are dispersed may be larger than the other perforations to further increase the power levels at which the narrow beam operating mode is achieved. Although a completely perforated generally-spherical cathode would appear to afford maximum efficiency it is apparent that cathodes of different configurations and cathodes having imperforate portions remote from the aperture can be caused to operate successfully in the narrow beam mode. The size, configuration and location of the auxiliary electrode may vary within wide limits depending on the specific application for which the discharge device is to be used. The spacing between the cathode and the auxiliary electrode is not critical. Suitable operation has been achieved for spacing distances ranging between 0.25 to 2 times the cathode radius. Both annular rings and cylinders having inside diameters greater than the diameter of the beam have been used with success. Although there is no limit on the size of the ionization chamber, the chamber should be large enough to permit the formation of a "cathode dark space" on the exterior of the cathode. When a separate anode is provided (for example, the anode 58 of FIG. 3), its location is not critical as long as it lies outside the region normally occupied by the cathode dark space. It will be apparent to those skilled in the art that other embodiments and modifications may be made in the disclosed apparatus without deviating from the scope of the invention set forth in the following claims,

What is claimed is:

1. An electronic discharge device comprising in combination

means for generating a narrow electron beam in an ionizable gas having a low subatmospheric pressure, said generating means including a hollow cathode body defining a generally spherical cavity and having a perforated wall portion containing an aperture; and means for dispersing upon perforated portions of the body remote from the aperture the ions generated by and in conjunction with the electron beam which are attracted to the cathode, whereby the number of ions entering the cathode cavity through the aperture is reduced.

2. Apparatus as defined in claim 1 wherein said ion dispersing means comprises a member spaced from said cathode body and containing a through opening receiving said electron beam.

3. Apparatus as defined in claim 2 wherein said member comprises an auxiliary electrode, and further including biasing means causing said electrode to have a given potential relative to said cathode body.

4. Apparatus as defined in claim 3 wherein said generating means includes an anode, and further wherein said biasing means establishes an auxiliary electrode to cathode potential which is less than approximately 20% of anode to cathode potential.

5. Apparatus as defined in claim 4 wherein the potential of the auxiliary electrode is positive relative to cathode potential.

6. Apparatus as defined in claim 4 wherein the auxiliary electrode and the cathode body are at equal potential.

7. Apparatus as defined in claim 1 wherein said generating means includes a housing provided with a through opening receiving said electron beam.

8. Apparatus as defined in claim 1 wherein said ion dispersing means comprises a generally concave surface on said cathode body, said concave surface being perforated and containing said aperture.

9. Apparatus as defined in claim 8 wherein said ion dispersing means further includes auxiliary electrode means spaced from said cathode adjacent said aperture, and means establishing a potential relationship between said cathode and said auxiliary electrode.

10. Apparatus as defined in claim 1 wherein said cathode body has a generally spherical configuration.

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DAVID J. GALVIN, *Primary Examiner.*