United States Patent

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[54] **PRODUCTION AND UTILIZATION OF HIGH-DENSITY PLASMA**
15 Claims, 2 Drawing Figs.

[52] **U.S. Cl.** **313/83,** 176/11, 313/74
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[50] **Field of Search** 313/74, 83

[56] **References Cited**
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2,574,655	11/1951	Panofsky et al.	313/74 X
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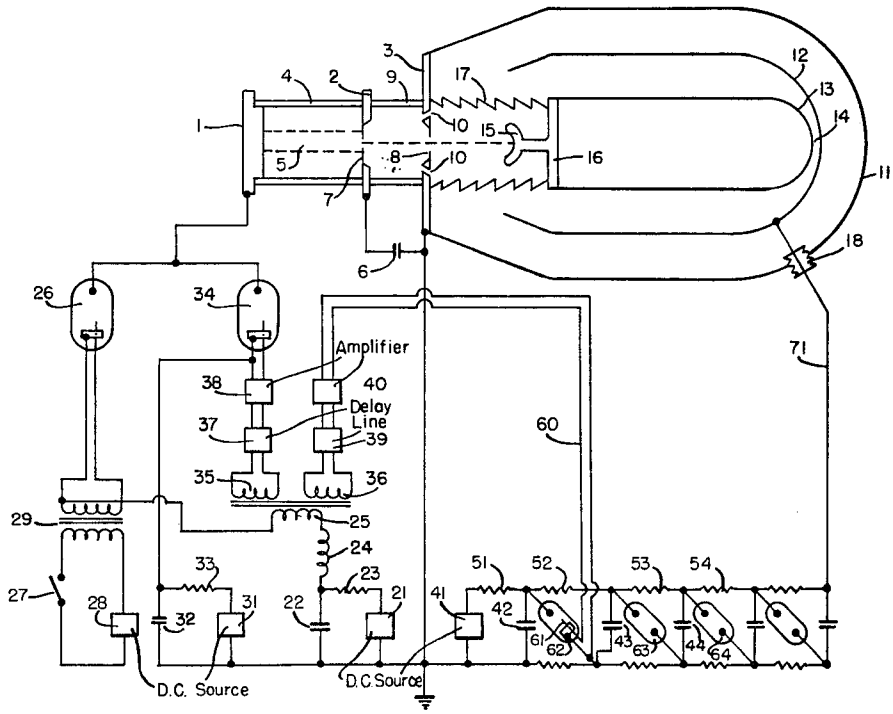
ABSTRACT: The disclosure relates to apparatus for producing pulsed beams of electrons which, by linear pinched techniques, are focused down to very small diameters, for example, to less than 1 millimeter, thereby making possible the generation of an extremely high power density on a selected target.



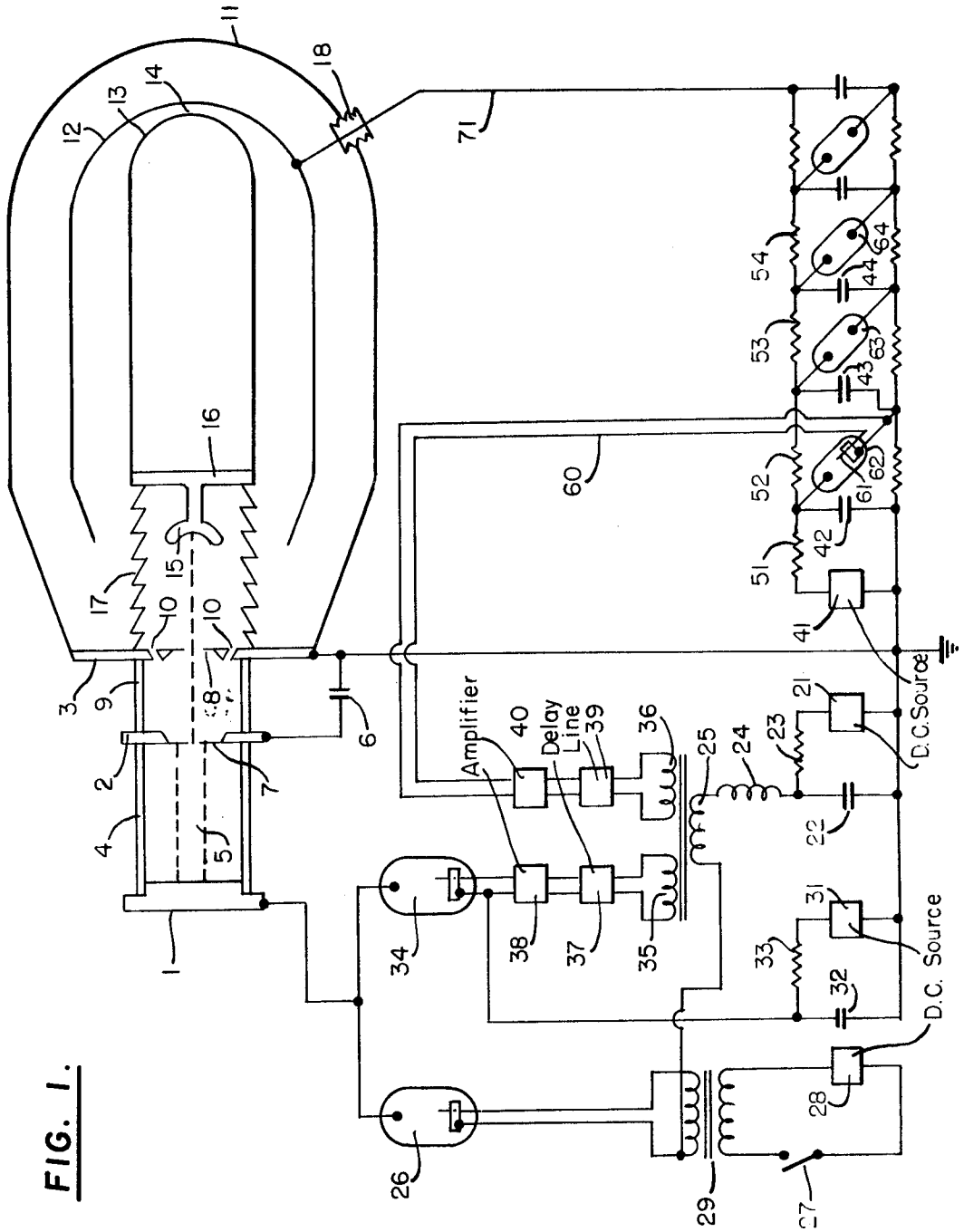


FIG. 1.

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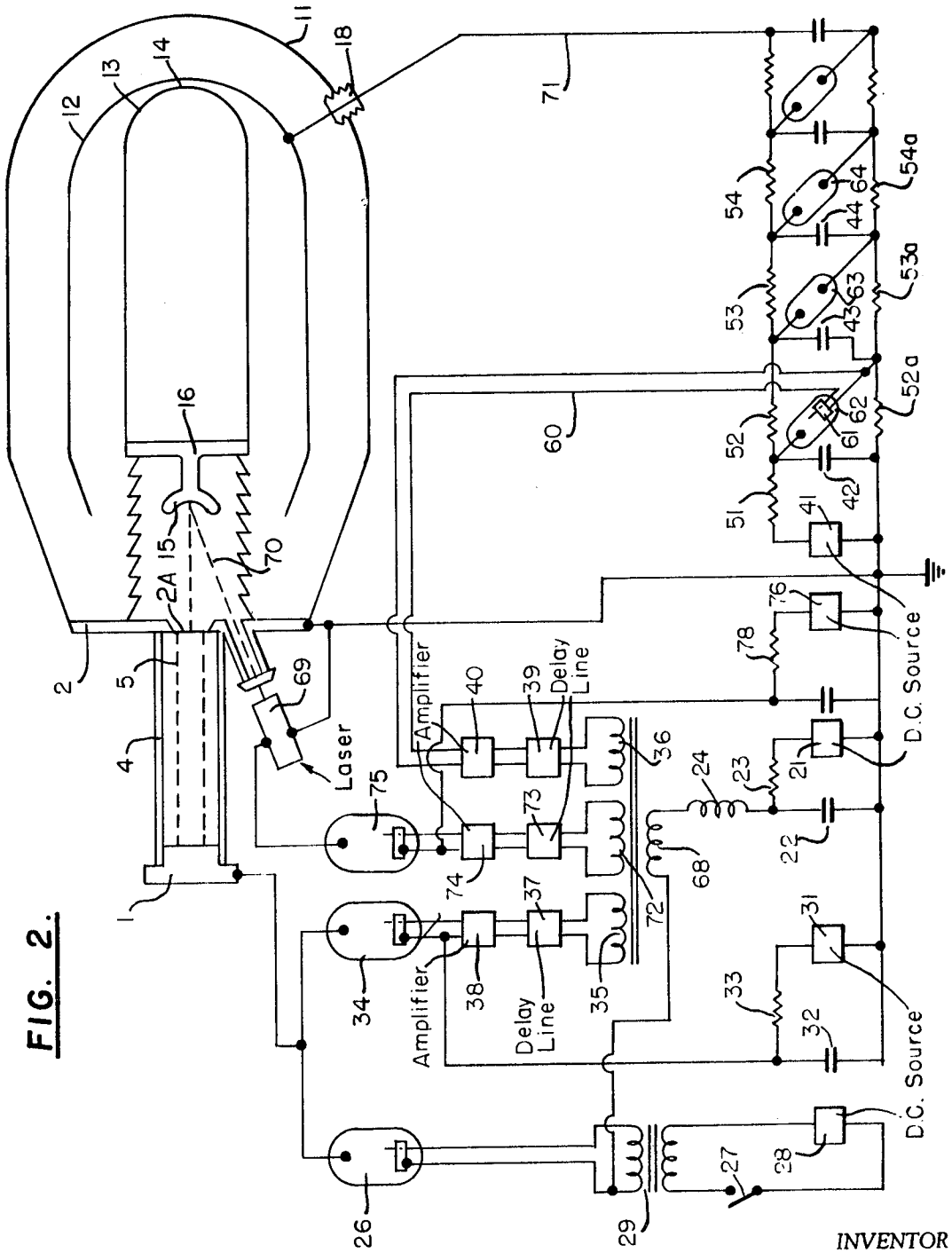

FIG. 2.

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PRODUCTION AND UTILIZATION OF HIGH-DENSITY PLASMA

This application is a continuation in part of my prior copending application, Ser. No. 657,986 filed Aug. 2, 1967, entitled "Production and Utilization of High-Density Plasma."

BACKGROUND OF THE INVENTION

It has previously been known that a linear pinch may be created by a pulsed discharge. Such a linear pinch produces a self-magnetic field and tends to pinch and thus concentrate the flow of electrons in the pinch. This makes possible the production of high-density plasmas, a particular application of which includes the production of transuranic elements in greater than microgram quantities. Such elements are useful as nuclear fuels, radioactive tracer elements, and as radiation sources for the irradiation of various materials.

My prior copending application, Ser. No. 569,549, filed July 19, 1966, entitled "Method of and Apparatus for Producing a Highly Concentrated Beam of Electrons" now U.S. Pat. No. 3,510,713, teaches that if an electron beam is produced in alignment with the pinch, the pinch will narrow down and further concentrate the electron beam. The present application is an improvement upon that arrangement.

It is generally observed that the field emission from cold cathodes produced by applying very high voltages in tubes of the kind illustrated in my prior copending Pat. applications Ser. No. 569,549 filed July 19, 1966, and Ser. No. 597,392 filed Nov. 28, 1966, entitled "Method of and Apparatus for Producing a Highly Concentrated Beam of Electrons" now U.S. Pat. No. 3,516,906, is erratic both in time and also in location of the emitting areas. The emission from the rounded end of a one-sixteenth-inch diameter wire is in the form of small diameter beams which move about very rapidly within a cone of aperture of the order of 30°. This is believed to indicate that the field emission is enhanced wherever a positive ion is approaching the field emitting surface, or wherever there is a small amount of plasma located next adjacent to the cathode surface.

In order to cause the field emission to be directed within a narrow cone toward the target, it is proposed to use arrangements described and claimed in this application as follows.

SUMMARY OF THE INVENTION

The present invention involves improvements in the apparatus, and more particularly in that portion of the apparatus where the electron beam generator feeds the pinched discharge tube, in order to deliver a more narrowly collimated beam into the pinched discharge tube.

DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic drawing of one form of the invention.

FIG. 2 is a schematic drawing of a modified form of the invention.

COMPLETE DESCRIPTION OF THE INVENTION

In one embodiment, shown in FIG. 1, instead of having a single electrode at the junction between the pinch tube and the electron beam generator, I employ two electrodes suitably interconnected to improve the operation of the apparatus, and I may further have a concave surface for the cathode of the electron beam generator. In another embodiment, shown in FIG. 2, I project a laser beam upon a small central portion of a cathode surface in the electron beam generator.

In the embodiment illustrated in FIG. 1, as will be described in greater detail later, a voltage is applied between the target 1 and the electrode 2 in such a manner as to produce ionization of the gas between these electrodes inside of the tube 4. Then an additional and more sharply peaked voltage is applied between those electrodes which produces a pinched discharge in the preionized gas along a channel 5. By virtue of the location of the condenser 6 between the electrode 2 and ground, the voltage applied between electrode 2 and the electrode 3 is such that ions from the pinched discharge 5 which pass through the small aperture in the thin diaphragm 7 are accelerated toward the electrode 8 and a few of those ions pass through the small aperture in the thin diaphragm 8. While the discharge in the tube 4 is pinching into the channel 5, the machine for producing intense pulses of relativistic electrons contained in tank 11 is actuated thereby producing a stream of relativistic electrons from the cathode 15 through the two diaphragms and into the pinched discharge 5.

In the embodiment illustrated in FIG. 2, as will be described in greater detail later, a laser 69 projects a pulsed laser beam 70 onto a small area on the cathode 15. In one form of this embodiment, a small amount of material having a lower density than the metal comprising the cathode 15 may be attached to a small area on the cathode 15 in order to enhance the production of plasma near the cathode by the laser pulse.

Returning now to the embodiment illustrated in FIG. 1, a power supply 21 is used for charging a condenser 22 through a resistor 23. The condenser is connected through an inductor 24 and a transformer 25 to a triggered gap, or thyratron or other high voltage valve 26. The device 26 is triggered by closing the switch 27 which connects the high voltage from the power supply 28 to a transformer 29. This applies a potential to the target 1 of the pinch tube 4 for the purpose described in the next paragraph.

The magnitude of the inductor 24 is selected to slow down the discharge in the pinch tube 4 enough to produce ionization throughout the tube but not to pinch down the discharge within less than about 10 to 100 microseconds, if at all. This is called a preionization and assists in readying the conditions inside the pinch tube so that when the condenser 32 is connected across the tube, a well-known pinch will form promptly, i.e., within less than about 5 microseconds.

The power supply 31 charges the condenser 32 through the resistor 33. The condenser is connected to the triggered gap or other valve 34, to apply high voltage in a steeper pulse which causes the gas in 4 to pinch down to an ionized column 5.

The transformer 25 has two secondary windings, 35 and 36. The output from winding 35 is connected through a delay line 37 to the amplifier 38, which is connected to the triggering device 34. The other winding 36, is connected through a delay line 39, to an amplifier 40, which is connected to the triggering device 62, which fires the high energy machine.

The delay in either 37, or 39, is set so that the high-energy electron pulse from cathode 15 is produced just before the pinch at 5 has drawn down to its minimum diameter of ionized column. For most dimensions of the parts of the machines and values of the electrical constants in the various parts of the complete equipment, the delay in the delay line 39 should be set at zero or this delay line should be removed and the delay in delay line 37 should be set at some value less than about 10 microseconds.

One example of a machine for producing intense pulses of relativistic electrons is shown in the figures.

Inside of a tank 11 there are suspended two coaxial cylindrical electrodes 12 and 13. The rounded caps on 12 and 13 are held much closer to each other at the gap 14 than the distance elsewhere between 12 and 13.

At the left end of the inner electrode 13 is a high-voltage electrode 16 which is supported on an insulated bushing 17. All of the tank except inside of the bushing 17 is filled with an insulator such as oil or other insulating fluid or gas. The inside of the bushing 17 is evacuated to pressures less than one-tenth micron by means of suitable vacuum pumps.

The intermediate electrode 12 is charged to a high voltage through a wire connected at 71 which extends through bushing 18 in the wall 11. This wire is connected to a source of high voltage shown in the lower part of the figure and may be constructed in any of many ways familiar to those skilled in the art.

The direct current supply 41 of potential of the order of 50,000 or more volts charges a bank of condensers 42, 43, 44,

etc. in parallel through high resistances 51, 52 and 53 which are preferably more than 1,000 ohms each.

In the figure there are only four condensers, 42, 43, etc., shown together with their associated spark gaps 62, 63, 64, etc., and resistors 51, 52, etc. In actual practice, more condensers with associated components must be used, for most applications numbering between 20 and 200 such stages. In the following description it should be understood that a larger number of stages than shown in the figure are to be used.

Shown at 62 is a triggering device which is a spark gap in which the outer one of the electrodes has a hole in it along the axis of the two electrodes. Inside of the hole is held a wire 61, the end of which is near the opening towards the other electrode. This wire is insulated so that when a high voltage is suddenly applied to it through a wire 60, a small spark will jump from the end of 61 to the surrounding outer electrode. This causes a sparkover of the gap and suddenly connects the upper terminal of condenser 42 to the lower terminal of condenser 43 and applies a voltage across the next spark gap at 63 which is much greater than the breakdown voltage of that gap. This overvolts the next spark gap at 64 even more and so on, sparking over the next of the spark gaps and suddenly connects all of the condensers, 42, 43, etc., in series, applying the total voltage to the intermediate electrode 12. Instead of the triggered gap described above, a thyraton or any of the high-voltage valves familiar in the art may be used.

When the electrode 12 attains a sufficiently high charge by reason of the condensers 42, 43, etc., being connected thereto, the high voltage discharges across the gap 14 to the tube 13, thus resulting in a discharge from the high-voltage electrode 15, establishing a concentrated beam of electrons which is projected along the axis of the tube 17, first passing through the diaphragm 8 which is sufficiently thin as to allow the electrons to pass therethrough.

Instead of using the rounded end of a wire as the cathode, use can be made of a concave metal surface such as illustrated at 15. In front of this cathode are located two thin metal sheets 7 and 8 in each of which there is (or alternatively may be) a small aperture on axis. These sheets are mounted on electrodes 2 and 3 respectively which in turn are separated by a section of glass pipe or other insulating materials 9. Electrode 7 is connected to electrode 8 through a condenser 6.

In operation, the linear pinch discharge is produced between electrode 1 and electrode 7 with means previously described. This discharge projects a few positive ions through the aperture in the sheet 7 and the application of voltage between electrode 7 and the electrode 8 causes a buildup of voltage across the condenser 6. The potential difference across the condenser 6 produces an electric field between 7 and 8 which accelerates the positive ions towards and through the aperture in 8 and some of these positive ions continue toward the surface of the cathode 15. The enhancement of the field emission at 15 produces field emission which is directed toward and through the thin sheets 7 and 8 into the linear pinch discharge 5 which has been produced inside of the tube 4. Small pumping apertures 10 are provided around the edge of electrode 3 inside of 9 in order that the same vacuum pumps which keep the high-voltage bushing 17 evacuated will keep the space inside of 9 evacuated also.

The capacity of the condenser 6 should be larger than either the capacity of the condenser 22 or the condenser 32 which are used for producing the linear pinch discharge.

Instead of the condenser 6, a resistor can be used whose resistance is small enough to avoid seriously disturbing the formation of the linear pinch discharge and whose current-carrying capacity is sufficient to withstand the pulsed discharge with which the linear pinch is formed. For example, if a linear pinch current of 50,000 amperes is produced with a condenser discharge at 15 kilovolts, a desirable value of the resistance would be of the order of one-tenth ohm and the resistance might be made of pieces of boron carbide. However, there are many other variations of material and values of resistance which would be quite satisfactory and would be familiar to those skilled in the art.

In FIG. 1 the firing of the triggered gaps 26 and 34 applies a positive potential to electrode 1 causing current to pass through the gas to electrode 7 which continues through condenser 6 to ground. Passage of current through the condenser causes buildup of voltage across the condenser which voltage is applied between electrodes 7 and 8. The appearance of voltage on the condenser and therefore between electrodes 7 and 8 applies an electric field which accelerates ions emerging through electrodes 7 and 8.

Turning now to the embodiment illustrated in FIG. 2, the components serving similar functions to those in FIG. 1 are similarly numbered. The transformer 68, however, has three secondaries, 35, 36 and 72 instead of the two secondaries of the transformer 25 of FIG. 1. Closing the switch 27 triggers the device 26 and lets condenser 22 discharge through the primary of the transformer 68 and trigger the device 34 resulting in the pinched discharge 5 in the tube 4. The pulsing of the transformer 68 also triggers the device 75 through the secondary 72, the delay line 73 and the amplifier 74, and allows the condenser which has previously been charged from the power supply 76 through the resistor 78, to energize the laser 69 and make it project a pulsed light beam onto a small area on cathode 15. The impact of the laser light pulse on material at the surface of the cathode 15 produces some plasma adjacent to the cathode. The pulsing of the transformer 68 also triggers the device 62 through the secondary 36, the delay line 39 and the amplifier 40 which fires the high-energy machine just as before in the embodiment shown in FIG. 1.

In connection with FIG. 2, the application of laser light on the cathode 15 can be made intense enough to vaporize some of the material on the cathode 15 itself and/or some of the material lying on the surface of the cathode 15. The production of ionized material provides positive ions which locally intensify the electric field and thereby increase the field emission from that local area.

In this embodiment shown in FIG. 2, the thin diaphragm 2A in electrode 2 does not have any aperture in it. Since the diaphragm 2A is a thin metallic diaphragm, electrons may pass therethrough even though there is not an aperture therein.

The delays to be used in the three delay lines 37, 39 and 73 are to be adjusted to that the pinching of the discharge 5 has advanced to the degree where it produces the greatest intensity of pinching of the high-energy electron beam coming from the cathode 15, at the instant that the high-energy machine applies its high potential to the cathode 15, and the laser has just projected its light pulse onto the surface of the cathode 15 producing plasma adjacent to that cathode.

I claim:

1. Apparatus for directing a narrow electron beam toward a target comprising:

an electron emitting cathode,

an anode for receiving electrons from said cathode, said anode comprising said target,

means for producing plasma adjacent to a small portion of the surface of the cathode to localize the emissive area of the cathode and thus concentrate the stream of electrons from the cathode,

electrode means positioned between the anode and the cathode, and

means for producing a pinched discharge between said electrode means and said anode to thereby further concentrate the stream of electrons.

2. Apparatus as defined in claim 1 in which said electrode means is a metallic sheet through which electrons passing from the cathode pass;

said means for producing a pinched discharge including means for applying a potential between the anode and said sheet to create said pinched discharge;

an evacuated envelope, one wall of which is said sheet, surrounding said cathode;

and an enclosure, of which one wall is said sheet, for the said pinched discharge.

3. Apparatus of claim 1 in which the plasma producing means directs a laser beam onto the surface of said cathode.

4. The apparatus of claim 3 in which said cathode is of concave shape.

5. The apparatus of claim 2 in which the metal is thin and imperforate.

6. The apparatus of claim 2 having means for ionizing the gas in the space between said electrode means and said anode prior to the production of the pinched discharge.

7. Apparatus for directing a narrow electron beam toward a target comprising:

an electron emitting cathode,

an anode for receiving electrons from said cathode,

two spaced electrodes electrically insulated from each other and each comprising a thin sheet having an aperture therein, said apertures being positioned between said cathode and said anode to allow electrons from the cathode to pass through said apertures to said anode,

means for producing a pinch between said anode and the nearest of said two electrodes,

and means cooperating with said two spaced electrodes to establish a field therebetween.

8. The apparatus as defined in claim 7 in which said last-named means includes means that establishes an electromotive force between said two spaced electrodes for accelerating ions toward said cathode thereby concentrating the electrons leaving said cathode into a narrow beam.

9. The apparatus of claim 8 in which said last-named means comprises an impedance connected across the electrodes and an electrical circuit for passing current through the impedance.

10. The apparatus of claim 9 in which the impedance is a condenser.

11. The apparatus of claim 9 in which the impedance is a resistor.

12. The apparatus of claim 7 in which said cathode is concave shaped.

13. Apparatus for directing a narrow electron beam toward a target comprising:

an electron emitting cathode,

an anode for receiving electrons from said cathode, said anode comprising said target,

means for directing a laser beam onto a small portion of the surface of the cathode to localize the emissive area of the cathode and thus concentrate the stream of electrons emitted by the cathode,

electrode means positioned between the anode and the cathode, and

means for producing a pinched discharge between said electrode means and said anode to thereby further concentrate said stream of electrons.

14. Apparatus as defined in claim 13 in which said electrode means is a metallic sheet through which the electrons passing from the cathode pass;

said means for producing a pinched discharge including means for applying a potential between the anode and said sheet to create said pinched discharge;

an evacuated envelope, one wall of which is said sheet, surrounding said cathode;

and an enclosure of which one wall is said sheet, for the said pinched discharge.

15. Apparatus for directing a narrow electron beam toward a target comprising:

an electron emitting cathode,

an anode for receiving an electron beam from said cathode, said anode comprising said target,

means for directing an ion beam onto the surface of the cathode to localize the emissive area of the cathode and thus concentrate the stream of electrons from the cathode,

electrode means positioned between the anode and the cathode, and

means for producing a pinched discharge between said electrode means and said anode to thereby further concentrate said stream of electrons.