

Oct. 29, 1968

K. L. CHOPRA ET AL

3,408,283

HIGH CURRENT DUOPLASMATRON HAVING AN APERTURED ANODE
POSITIONED IN THE LOW PRESSURE REGION

Filed Sept. 15, 1966

2 Sheets-Sheet 1

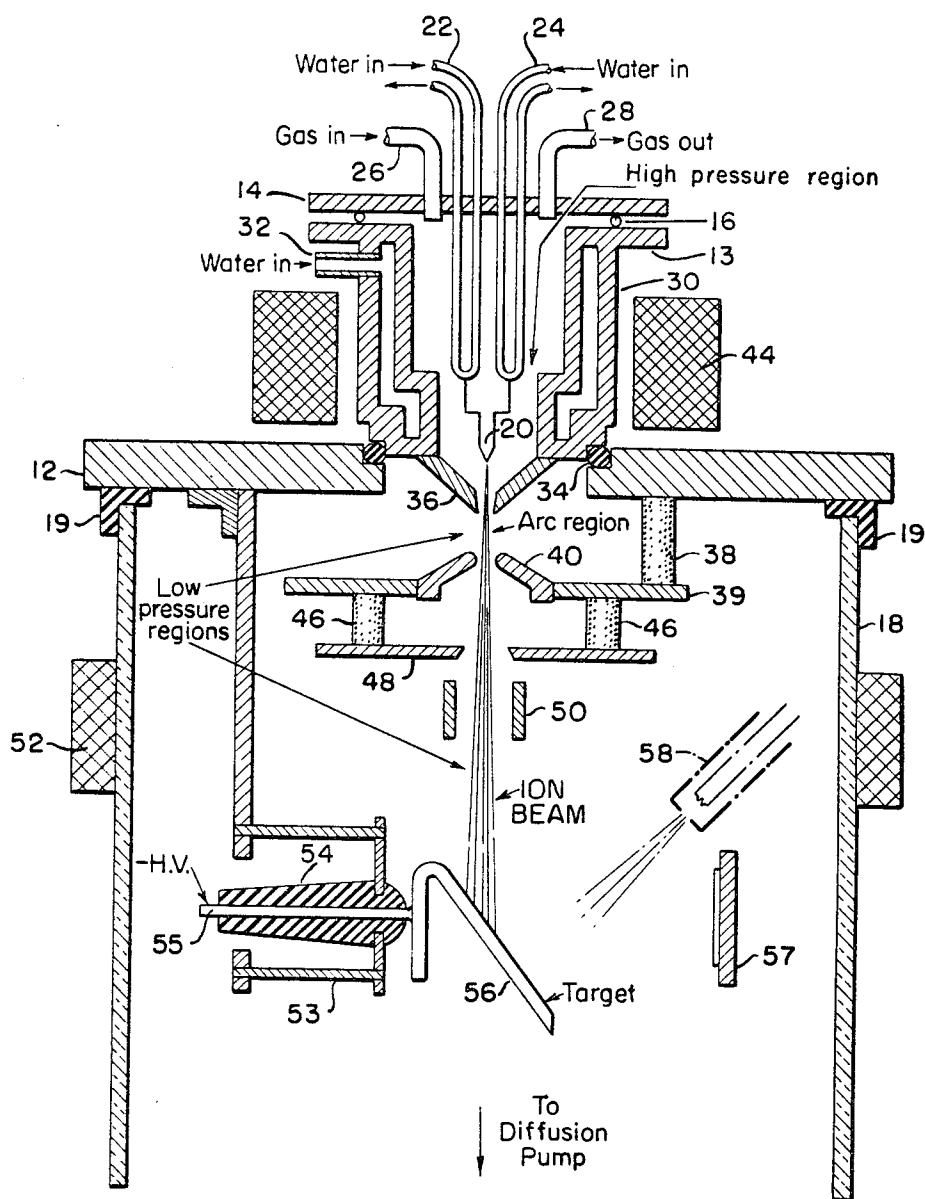


FIG. 1

INVENTOR.
KASTURI L. CHOPRA
MYRON RONALD RANDLETT
BY
Forney, Jenney & Hildreth

ATTORNEYS

Oct. 29, 1968

K. L. CHOPRA ET AL

3,408,283

HIGH CURRENT DUOPLASMATRON HAVING AN APERTURED ANODE
POSITIONED IN THE LOW PRESSURE REGION

Filed Sept. 15, 1966

2 Sheets-Sheet 2

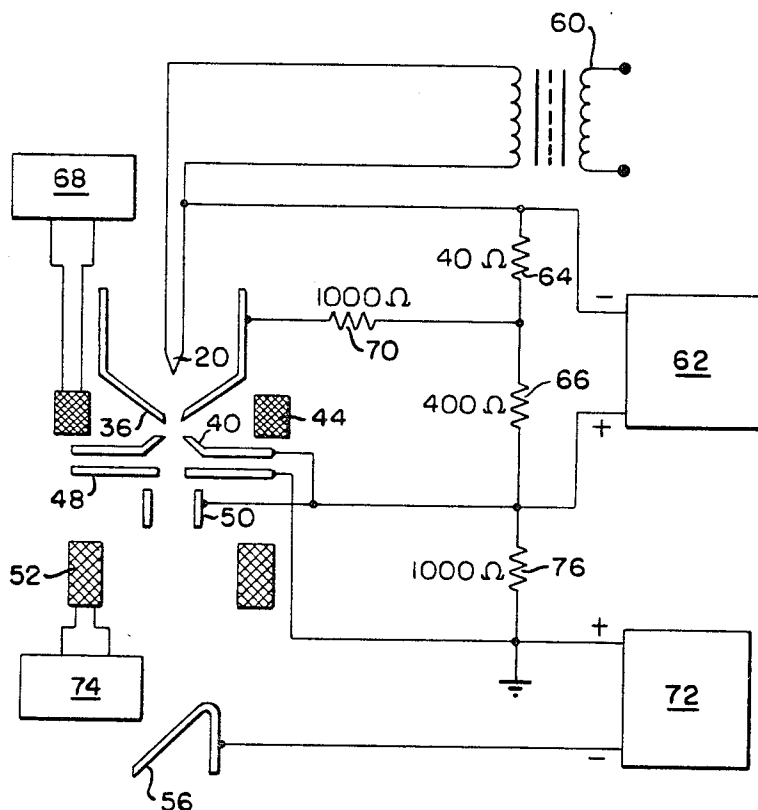


FIG. 2

INVENTOR.
KASTURI L. CHOPRA
MYRON RONALD RANDLETT
BY

Kerway, Jerney & Hildreth

ATTORNEYS

1

3,408,283

HIGH CURRENT DUOPLASMATRON HAVING AN APERTURED ANODE POSITIONED IN THE LOW PRESSURE REGION

Kasturi L. Chopra, Lexington, and Myron Ronald Randlett, North Wilmington, Mass., assignors to Kennecott Copper Corporation, New York, N.Y., a corporation of New York

Filed Sept. 15, 1966, Ser. No. 579,599

4 Claims. (Cl. 204-298)

This invention relates in general to duoplasmatrons, a name which has been applied to high intensity arc type ion sources. More particularly, the invention is concerned with improvements in duoplasmatrons of the type developed by von Ardenne.

Considerable development of duoplasmatrons has taken place since the early work of von Ardenne. Although the basic duoplasmatron was considered to constitute a remarkable tool for many purposes, changes have been made to adapt the apparatus to specific problems. Most of these changes have not concerned basic elements of the device but have involved redesign of electrode configuration, the provision or modification of magnetic fields to better control the ion beam which is produced and the choice of more suitable materials for the specific applications.

Generally, in a duoplasmatron, there is a high pressure and a low pressure region. An anode surrounds a cathode in the high pressure region and an arc is struck between the anode and the cathode. Gas, typically one of the rare gases, is introduced into the high pressure region and it is ionized by the arc to create a plasma. Usually, ionization is enhanced by an axial magnetic field which further functions to confine the plasma to the center of the system.

The anode is provided with an aperture aligned with the cathode in such a fashion that ions may be extracted through the aperture. From the aperture the ions emerge into a low pressure chamber in which chamber they are utilized for any one of numerous operations. For example, they may be directed upon a target to sputter material from the surface of the target; they may be utilized for melting or sintering material; or they may be used for degassing, selective heating or any one of numerous other applications.

The arc sets up rather large temperature gradients and these gradients give rise to a flow pattern of both ionized and neutral gas which is extremely complicated but which tends to remove ions from the region of the anode aperture. The relatively thin concentration of ions in the neighborhood of the aperture makes difficult the extraction of an intense high current ion beam. Much effort has been expended to overcome this problem by sophisticated electron-optical design and by the use of auxiliary electronic components. However, these expedients have been successful only to a limited degree. It is, therefore, the primary object of the present invention to improve intense ion beam current capabilities in duoplasmatrons.

A further object of the present invention is the elimination of sophisticated electron-optical components from, and the general simplification of, duoplasmatrons.

A still further object of the present invention is the increase of flexibility in, and multiplication of areas of usefulness of, duoplasmatrons.

Still another object of the present invention is the reduction of cost and complexity of duoplasmatrons.

Generally, the present invention consists in a revamping of fundamental arrangements of apparatus in a duoplasmatron. Because the conventional duoplasmatrons initiate and maintain an arc discharge in the high pressure region of the device, problems with insufficient con-

2

centration of ions at the anode aperture have arisen, as noted above. In the present invention, the arc discharge is initiated and maintained at least in part in the low pressure region as well as in the high pressure region.

5 The arrangement of electrodes is such that the cathode is disposed in the high pressure region and the apertured anode is located in the low pressure region of the device. As a result, the flow of neutral and ionized gas occurring with the generation of heat by the arc discharge is confined to the aperture separating the high and low pressure chambers. Thus, a high concentration of ionized gas is available in the region of generation of the ion beam and the plasma conditions are steadier than those previously obtainable. For a better understanding of the present invention, together with other and further objects, features and advantages, reference should be made to the following detailed description of a preferred embodiment which should be read in conjunction with the appended drawing in which:

20 FIGURE 1 is a schematic sectional view of a duoplasmatron incorporating the present invention; and

FIGURE 2 is a schematic diagram illustrating electrical components and elements of the duoplasmatron.

15 In FIGURE 1 there is shown a base plate 12, typically of stainless steel, which divides the duoplasmatron into two regions. Although both regions are held under vacuum, as is common in duoplasmatron, the upper region is at a relatively higher pressure than the lower region. The upper region is defined by the base plate 12, an electrode flange 13 and a cover 14.

30 The upper region is shown in a somewhat schematic form, although it is to be understood that a total enclosure is utilized, as is indicated by the cover 14 and its vacuum-tight connection by a seal member 16 to the electrode flange 13. In a preferred embodiment, however, the evacuated upper region is limited to the small central volume shown, but a larger volume may easily be provided, if needed.

A second housing 18 encloses the lower region and the second housing is joined to the base plate 12 by means of resilient seals 19. The housing 18 may be of glass, stainless steel or other suitable material. The lower region is maintained at an extremely low pressure compared to that in the upper region.

45 In the upper region, mounted generally along the axis of the device is a cathode 20. The cathode 20 may be in the form of a tungsten filament and it is preferably supported upon water cooled leads 22 and 24. Obviously, inlet and outlet connections for the water are necessary and these are sealed through the cover 14. Moreover, the seals are such that the position of the cathode may be varied along the axis of the apparatus. For purposes of simplicity, neither the precise mounting nor the seals themselves are shown.

55 A gas inlet composed of the tubing 26 which is also sealed through the member 14 provides a supply of gas for the upper region. The gas is preferably one of the rare gases, for example, argon gas of 99.999% purity. The gas is passed through a cold trap to remove traces of water and oil and is then fed to the chamber through a needle valve. Here again, the details of the trap and needle valve are not illustrated.

60 An outlet tube 28 is provided for the gas and the outlet tube is sealed through the member 14 leading to a rotary pump. The pumping action and the adjustment of the needle valve are preferably set so that the pressure in the upper chamber is approximately 50 millitorr. Although the limits are not critical, the pressure in the upper chamber is generally maintained between 20 and 100 millitorr and the gas flow rate is approximately 1 liter per second.

Surrounding the cathode 20 is a generally cylindrical

intermediate electrode 30. The intermediate electrode is provided with water cooling as indicated by the inlet 32 and the hollow internal structure. At its lower periphery, a shoulder is formed and the shoulder butts against an O-ring 34 which, in turn, is retained in a complementing shoulder formed in a cylindrical opening in the base plate 12. Extending through the opening in the base plate 12 is a conical portion 36 of the intermediate electrode 30. The cone is preferably made of soft iron and an aperture is formed at the tip of the cone.

As was noted above, the upper region may be defined by the water-cooled intermediate electrode 30 and the cover 14 sealed to the flange 13. A "Niton" seal 16 is utilized to maintain vacuum and electrical isolation. Alternatively, a volume of the upper region may be increased by the sealing of a "Pyrex" flanged pipe between the filament flange and the intermediate electrode.

Depending from the base plate 12 as by means of insulating posts of which the post 38 is typical, is a flange 39 from the center of which a conical anode 40 rises. Like the cone 36, the conical anode 40 is made of soft iron and has an aperture formed in its tip. The apertures of both the intermediate electrode 36 and the anode 40 are preferably about 3 mm. in diameter. It is generally desirable to cool the anode 40, and, to this end, a hollow structure with water cooling may be provided by conventional means.

A concentrated magnetic field is set up by means of a solenoid 44 which surrounds the intermediate electrode. Actually, a permanent magnet might equally well be used, the major requirement being the capability of producing a magnetic field of about 3-5 kg.

A 450 ampere-turn solenoid has proven suitable and the solenoid may be cooled by compressed air, water, or in extreme situations, by liquid nitrogen. The two soft iron conical elements concentrate the magnetic field axially with the result that the magnitude of the field between the two apertures is approximately 10 kg. Beneath the anode 40 and depending from the anode flange 42 by means of insulating posts such as those illustrated at 46, is a reference electrode 48. The reference electrode 48 may be a simple metallic plate in which a central aperture of about 5 mm. in diameter is formed as will be explained in greater detail in connection with the subsequent figure of the drawing. This electrode is held substantially at ground potential in order to define the accelerating voltage precisely with respect to the target. Immediately beneath the reference electrode 48 is a cylindrical focusing electrode 50 which may be retained in position by any suitable insulating means. The focusing electrode is preferably in the form of a short cylinder of about 2 cm. in length and having an inner diameter of about 1 cm. The focusing electrode 50 is held at the same potential as the anode 40 and is effective to prevent divergence of the ion beam. A further precaution against the divergence of the beam caused by electrostatic repulsion may be employed. This is the solenoid 52 disposed about the lower chamber to provide an axial magnetic field. A solenoid of about 400 ampere-turns has been found to be effective.

Suspended from the base plate 12 within the low pressure chamber is a high voltage feed-through 53. The manner of suspension is not critical. An insulating standard such as the member 54 is suitable for high voltage isolation. A high voltage lead 55 is passed into the chamber 18 by means of a high vacuum insulating feed-through assembly and to the end of the lead is welded or otherwise firmly attached to a target 56. The target is disposed along the axis of the chamber and is at an angle of about 45° to the axis. Adjacent the target and displaced from the axis is a substrate 57. The target 56 is desirably water cooled. Should it be desired to deflect the ion beam, a magnetic field may be provided inside the chamber. Such an arrangement might be useful in directing the beam upon other targets for various applications. Moreover,

as is indicated in phantom at 58 an electron gun may be provided to spray a stream of electrons upon the target to neutralize charges that may be built up or simply to increase efficiency of operation particularly when the target is of insulating material.

To maintain the extremely low pressures required in the lower chamber, as is indicated by the legend, the lower chamber is connected to a diffusion pump or a vacuum titanium sublimation pump system. In a typical installation, a 4" oil diffusion pump having a liquid nitrogen cooled baffle has proven capable of producing a pressure of about 2×10^{-5} torr. The operation of the illustrated embodiment of the invention may perhaps be better understood by considering the electrical schematic of FIGURE 2. The filament 20 is heated by a high current low voltage power supply 60 at a power consumption of about 200 watts. A conventional transformer providing an output voltage of about 10 volts at about 40 amperes to the filament is more than adequate. Between the filamentary cathode 20 and the anode 40 the actual arc voltage is applied. This voltage is obtained from a source 62 which may be a 0 to 500 volt D.C. supply capable of providing current up to 10 amperes. As indicated above, the positive voltage output of the supply 62 is also applied to the focusing electrode 50. The intermediate electrode 36 is connected to a tap on the voltage divider composed of the resistors 64 and 66 disposed across the output of the power supply 62. The intermediate electrode serves to assist the initiation of an arc which generally is struck at some point determined by the electrons emitted by the cathode 20, the pressure of the gas supplied through the inlet 26 and the strength of the axial magnetic field produced by the solenoid 44. In this connection, the solenoid 44 is energized by a power supply 68 capable of supplying up to 50 volts D.C. at currents ranging from 0 to 10 amperes. A resistor 70 is interposed in the connection between the intermediate electrode 36 and the tap on the voltage divider across the power supply 62 to limit current to the intermediate electrode to a few milliamperes. Applied to the target 56 is a negative voltage of 1 to 10 kv. from a power supply 72 capable of supplying 0 to 12 kv. at currents ranging from 0 to 400 milliamperes. The electromagnet 52 may typically be energized from a power supply 74 of about the same design as the power supply 68. The reference electrode 48 is, of course, connected to ground and an isolating resistor 76 is connected from the reference electrode to the positive voltage terminal of the supply 62 which is connected to the anode 40 and the focusing electrode 50.

As is plain from an examination of FIGURE 1, the arc is initiated between the cathode 20 in the upper relatively high pressure chamber and the anode 40 in the lower relatively low pressure chamber. Generally speaking, a voltage difference of 70 to 100 volts will suffice to maintain an arc of about 10 amperes. Obviously, these figures may be varied by variation of the filament temperature, gas pressure, and strength of the axial magnetic field. A well-defined ion beam of current up to 0.5 amperes may be extracted and directed upon the target. The flow of both neutral and ionized gas is confined almost entirely to the apertures separating the upper and lower chambers. As a result, the plasma conditions are uniform and stable. Gas efficiency of the source, by which is meant the ratio of the number of ions to the number of neutral gas atoms as high as 70% has been realized.

In a typical application of the apparatus, thin films of metals and semiconductors are sputtered from the target 56 to the substrate 57. In a typical operation, the parameters were as follows:

Beam current=50 ma.
Accelerating voltage=2 kv.
Arc current=4 a.
Pressure (upper chamber)=50 millitorr.
Pressure (lower chamber)= 2×10^{-5} torr.

Upper magnetic field=10 kg.

Beam size=8 mm.

Substrate to target distance=8 cm.

Of course, deposition rates vary with the materials being sputtered. Some experimental data on various materials is listed below:

Material:	Deposition rate (A./min.)
Ag -----	405
Cu -----	260
Nb -----	150
W -----	150
Quartz -----	50
TiO ₂ -----	50

The actual mechanics of the plasma production in the present invention have not been described in detail because these mechanics are well-known and are not critical in the present invention. Generally, however, electrons emitted by the cathode are accelerated toward the anode by the electrostatic field formed between the cathode and the anode as well as, to a lesser extent, by the field existing between the cathode and the intermediate electrode. The other effective parameters such as the magnetic field have been mentioned above. The electrons are concentrated in a stream and the neutral gas which is introduced is formed into a plasma from which the ions are extracted through the apertures toward the highly negative target. It is common to refer to the plasma production as striking an arc. It should be noted, however that the gas which is introduced need not be argon since other gases, notably the rare gases, may equally well be used. Also, although the source of electrons has been indicated to be a tungsten filament, other materials such as molybdenum or oxide-coated cathode materials may be used.

Several of the metals which can be sputtered successfully as well as other materials have been mentioned. However, the basic requirement for a successful sputtering is simply that the target material be available in plate form. Basically, the well-defined ion beam of currents up to 0.5 amperes over an area of approximately 1 cm.² constitutes an improvement useful in numerous applications. The simple modular construction of the apparatus enhances the usefulness of the system. For example, should the need arise, the aperture sizes can be easily changed to provide a different beam size. Also, the electrode configuration is such as to eliminate the need for shields. The possibility of sequential sputtering using multiple targets and a deflecting magnetic field for the ion beam has been noted. Of course, such techniques as ion implantation, melting, degassing, sintering, or the heating of materials in bulk require little or no modification of the basic apparatus. Other and further applications and minor modifications will suggest themselves to those skilled in the art upon a reading of the foregoing specification. Therefore, the invention should be limited not to the details shown and described but only by the spirit and scope of the appended claims.

What is claimed is:

1. In duoplasmatron ion beam apparatus in which an arc is struck to form ionizable gas into a plasma from which an ion beam may be extracted, the combination of

a first chamber to which said gas is supplied, means for pumping said first chamber down to a relatively high pressure of said gas, a second chamber, means for pumping said second chamber down to a relatively low pressure, means including an intermediate electrode separating said first chamber from said second chamber, said intermediate electrode including a portion formed of soft iron through which a first aperture is formed for the passage of said ion beam, a cathode disposed adjacent one side of said intermediate electrode and within said first chamber, an anode disposed adjacent the other side of said intermediate electrode and within said second chamber, at least a portion of said anode being formed of soft iron through which a second aperture is formed for the passage of said ion beam, means for applying a moderately high potential of a first polarity between said cathode and said anode and a moderately low potential of said first polarity between said cathode and said intermediate electrode whereby said arc is struck between said anode and said cathode to form said plasma, and means for producing a magnetic field in the region of said apertures, said soft iron portions of said intermediate electrode and said anode concentrating said magnetic field about said apertures, whereby said ion beam is confined to a predetermined size and direction.

2. The apparatus of claim 1 including a target electrode disposed in said second chamber and aligned with said apertures in said intermediate electrode and said anode, and means for applying a very high potential of a second polarity between said cathode and said target electrode whereby said ion beam is directed upon predetermined discrete areas of said target electrode.

3. In apparatus as defined in claim 2, the combination of a reference electrode and a focusing electrode disposed in said second chamber between said anode and said target electrode, said reference electrode having a third aperture formed therethrough in alignment with the apertures of said intermediate electrode and said anode for the passage of said ion beam, said focusing electrode being generally cylindrical and having its axis aligned with said apertures for the further passage of said ion beam, means for holding said reference electrode at a reference potential and means for applying said moderately high voltage of said first polarity to said focusing electrode.

4. In apparatus as defined in claim 3, the combination of means for producing a second magnetic field about said second chamber to further confine and direct said ion beam, a source of electrons and means for directing said electron beam upon said target to neutralize the charge thereon.

References Cited

UNITED STATES PATENTS

2,934,665	4/1960	Ziegler -----	313—63
3,133,874	5/1964	Morris -----	204—298
3,238,414	3/1966	Kelly et al. -----	313—63
3,315,125	4/1967	Fröhlich -----	313—63

FOREIGN PATENTS

1,372,240	8/1964	France.
-----------	--------	---------

ROBERT K. MIHALEK, *Primary Examiner.*