

July 16, 1968

R. M. MOSESON

3,393,142

CATHODE SPUTTERING APPARATUS WITH PLASMA CONFINING MEANS

Filed July 30, 1965

4 Sheets-Sheet 1

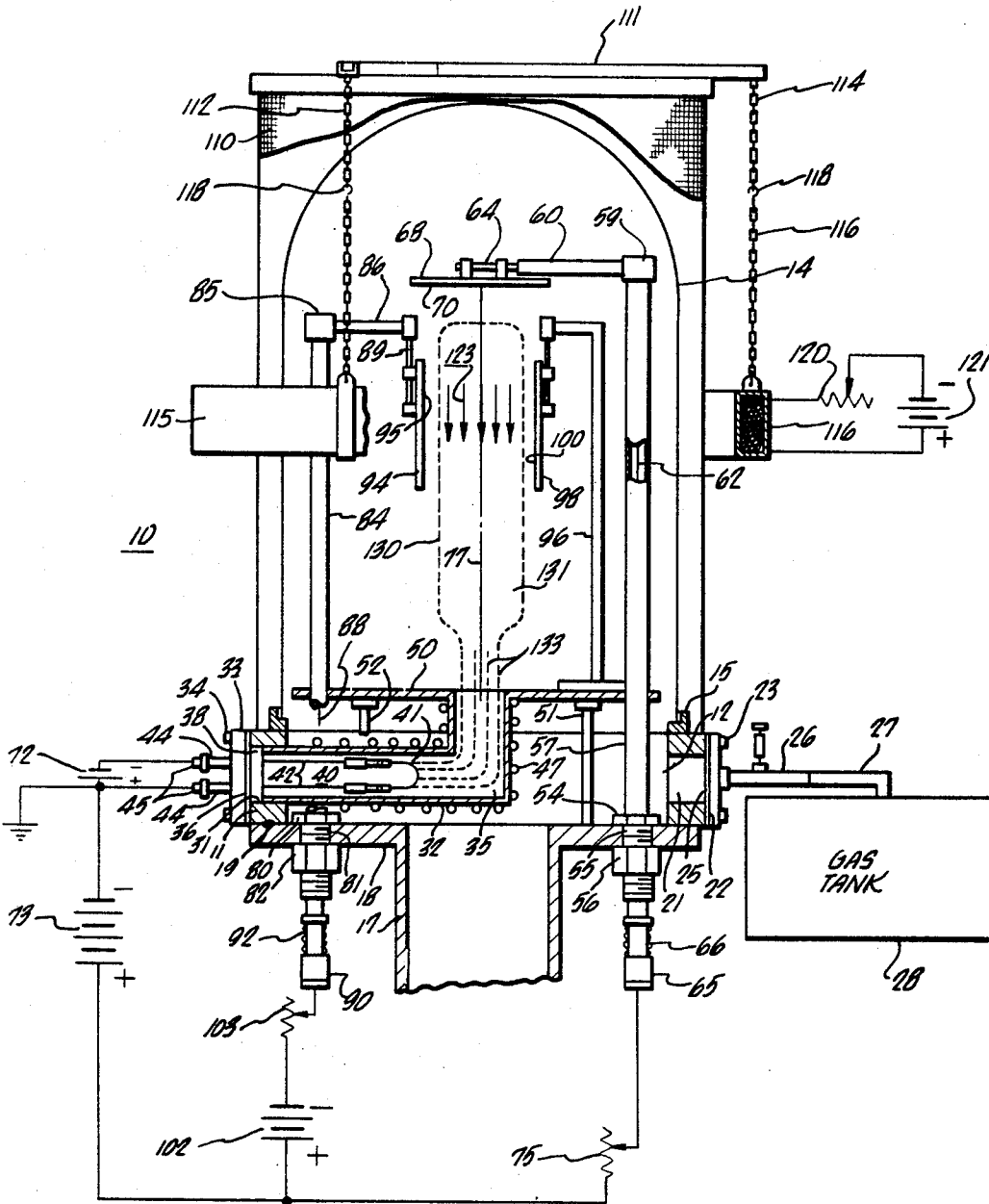


FIG. 1.

INVENTOR.
ROGER M. MOSESON
BY
Christie, Parker & Hale
ATTORNEYS.

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4 Sheets-Sheet 2

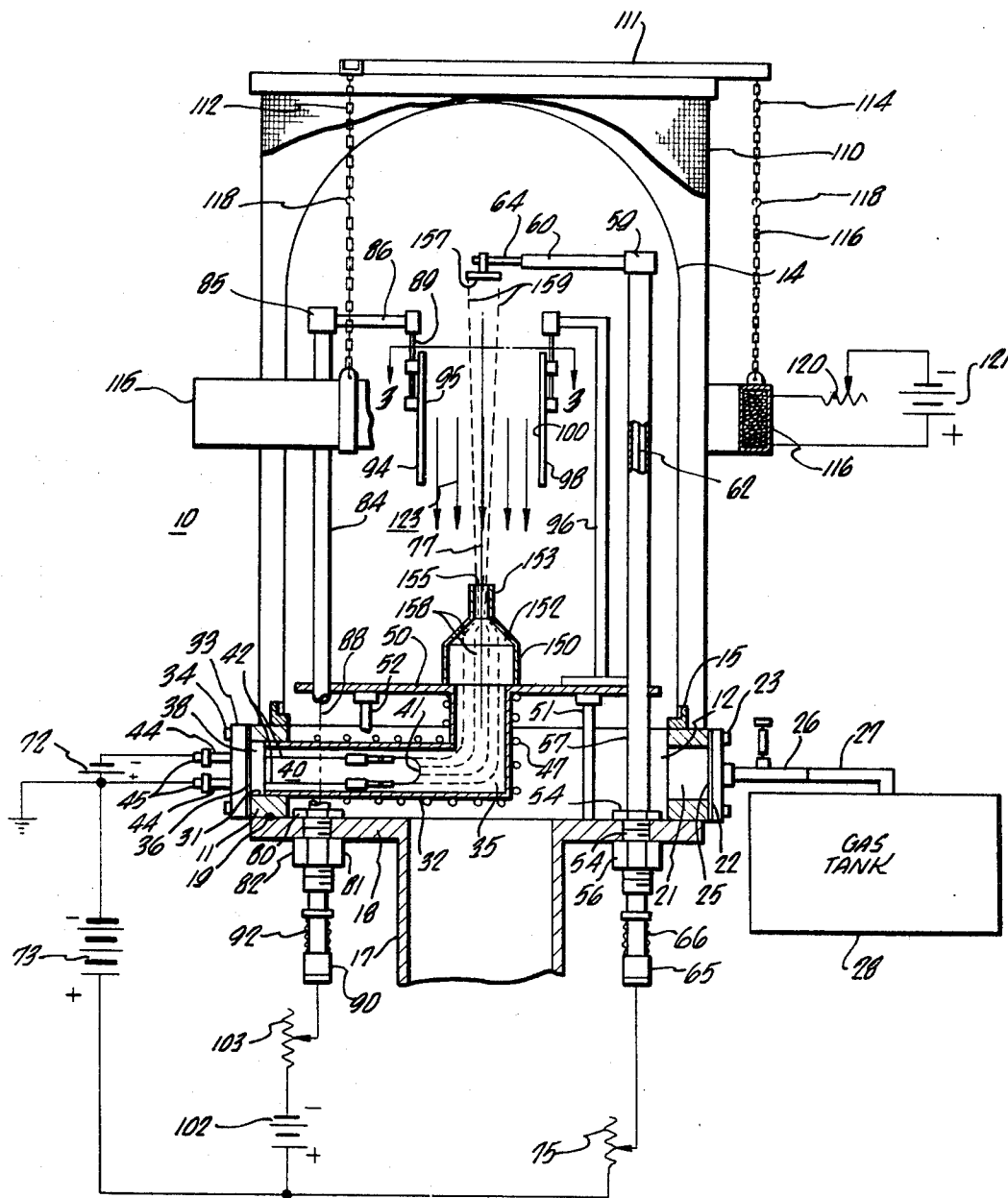


FIG. 2

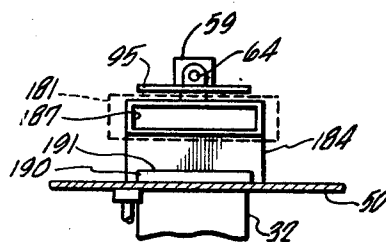
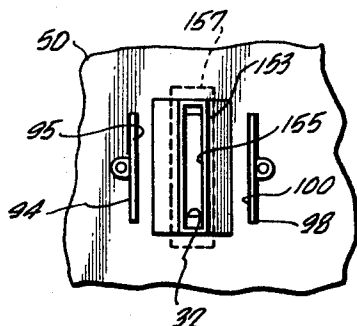
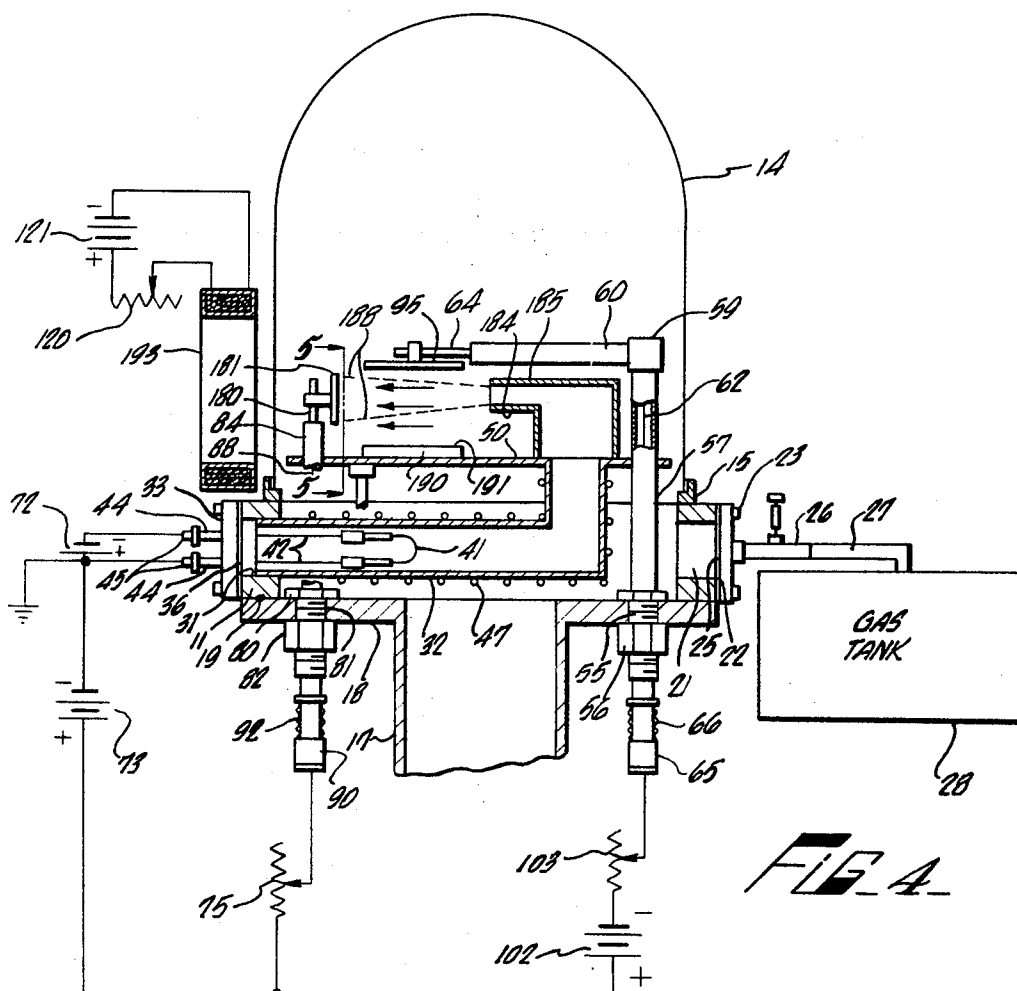
INVENTOR.
ROGER M. MOSESON
BY
Christie Parker & Hale
ATTORNEYS.

R. M. MOSESON

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4 Sheets-Sheet 3



INVENTOR.

INVENTOR.
ROGER M. MOSESON

BY

BY *Christie Parker Hale*
ATTORNEYS.

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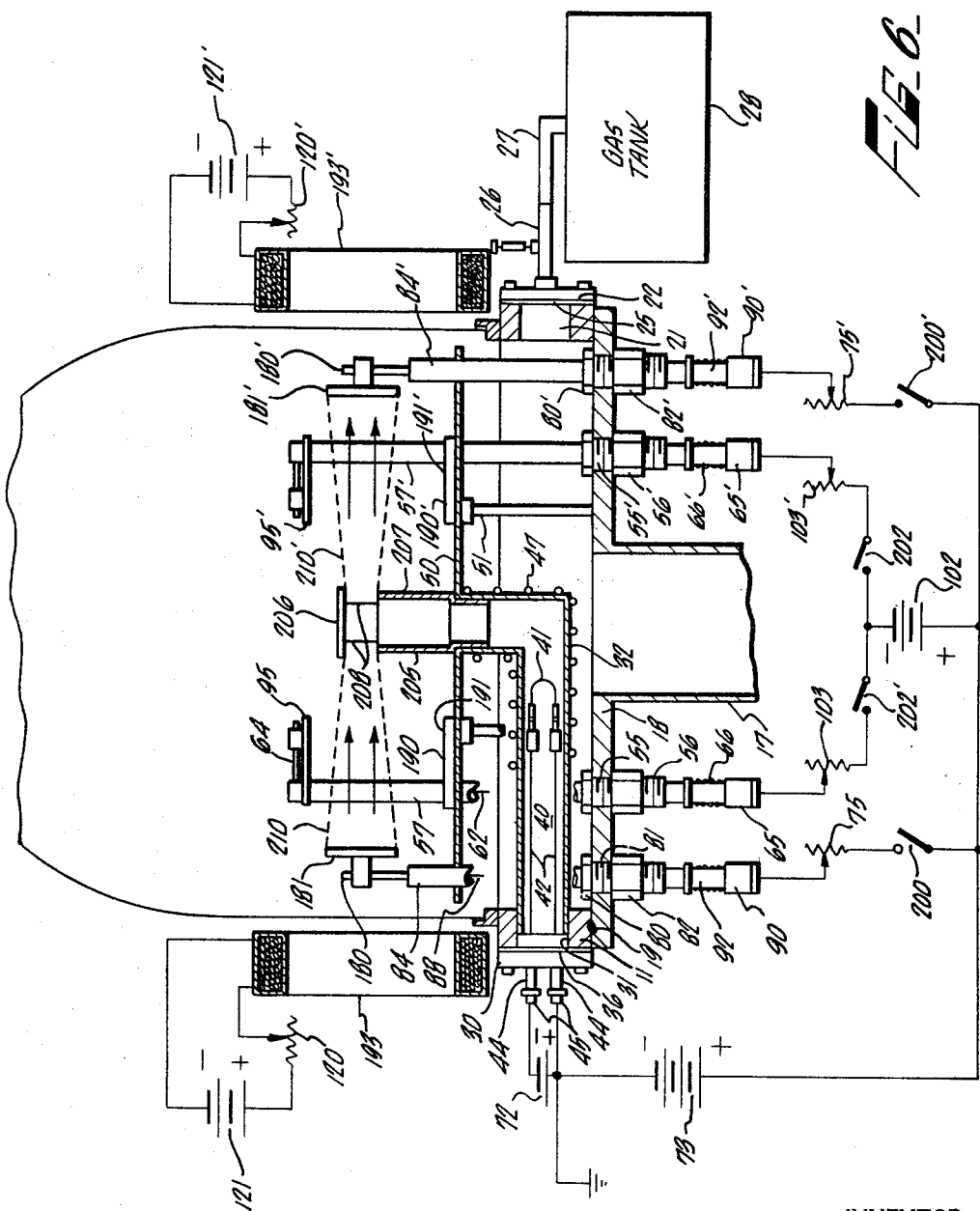
R. M. MOSESON

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4 Sheets-Sheet 4



INVENTOR.

INVENTOR.
ROGER M. MOSESON

BY

BY *Christie Parker Hale*
ATTORNEYS.

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**CATHODE SPUTTERING APPARATUS WITH
PLASMA CONFINING MEANS**

Roger M. Moseson, Rochester, N.Y., assignor to Consolidated Vacuum Corporation, Rochester, N.Y., a corporation of New York

Continuation-in-part of application Ser. No. 390,800, Aug. 20, 1964. This application July 30, 1965, Ser. No. 475,970

20 Claims. (Cl. 204—298)

This invention is a continuation-in-part of my previous patent application Ser. No. 390,800, filed Aug. 20, 1964 now U.S. Patent 3,305,473.

The subject invention relates to the art of sputtering, and more particularly, to apparatus for depositing thin films of material on a surface of a substrate by sputtering.

The phenomenon referred to as "sputtering" has been known for many years. Initially, this phenomenon was considered undesirable, since it caused blackening of tube walls, poisoning of cathodes and other deleterious effects in gas discharge and high vacuum apparatus and devices. More recently, sputtering has been developed to a highly sophisticated technique which permits the deposition of thin layers of material on various substrates. To date, films of nearly all metallic elements and of many alloys have been deposited on substrates of insulating material, metal or metal alloys. With the advent of miniaturization in electronics and related fields, sputtering techniques have become particularly valuable.

The most common form of prior-art sputtering apparatus was composed of a plane cathode and a plane parallel anode located in an evacuated vessel which contained sufficient ionizable gas molecules to sustain an electric discharge. The cathode was formed of the material to be sputtered and the anode was positively biased with respect to the cathode to establish an ion plasma between the anode and cathode. The substrate on which a thin film of the cathode material was to be deposited was located on a work support which was plane parallel to the cathode and was located between the anode and the cathode. Other forms of prior-art apparatus provided the anode in the form of an annular member located adjacent the cathode. The work support was then interposed between the anode member and an electrically biased ion accelerating electrode plate which extended parallel to the work support.

These prior art apparatus had the disadvantage of requiring considerable energy to provide a sputtering action of a satisfactory order.

The improvements of the subject invention considerably reduces the energy requirements of sputtering operations and increase the quality of sputtered film deposits.

A preferred embodiment of the invention provides an apparatus for depositing thin films of material on a substrate by sputtering. The apparatus comprises an enclosure and means for evacuating the enclosure and for providing an ionizable atmosphere therein. The apparatus further includes means for mounting the substrate in the enclosure and means for mounting an ion target of the material to be sputtered in the enclosure. The apparatus has means for establishing an ion plasma adjacent the ion target to sputter material from the ion target for the formation of films on the substrate. The means for establishing an ion plasma include an electron-releasing cathode. The cathode is located in a region shielded from the ion target and the substrate, so that material sputtered from the cathode does not deposit itself onto the substrate or ion target. According to the invention, a tubular structure extends from the cathode toward the anode where the ion plasma is formed to guide electrons released by the cathode to the anode. If desired, this tu-

bular structure may be provided with one or more bends.

The tubular structure need not necessarily be cylindrical, but may have a prismatic configuration or may be composed of cylindrical and of prismatic sections if desired.

The tubular means may also define apertures or nozzle structures which impart a desired configuration on the ion plasma produced by the electrons guided by the tubular structure. Positively biased anodes may be provided for attracting these electrons. In a further preferred embodiment, these anodes have a configuration which corresponds to the configuration of the above mentioned apertures or nozzles. In this manner, the anode or anodes in each apparatus cooperate in the formation of ion plasmas of desired configurations.

These and further features and embodiments of the invention will become apparent from the following detailed description of preferred embodiments thereof, illustrated by way of example in the accompanying drawings, in which:

FIG. 1 is an elevation, partially in section, of a sputtering apparatus in accordance with a first preferred embodiment of the invention, together with associated equipment;

FIG. 2 is an elevation, partially in section, of a first preferred modification of the apparatus illustrated in FIG. 1;

FIG. 3 is a view along lines 3—3 of the apparatus illustrated in FIG. 2;

FIG. 4 is an elevation, partially in section, of a second preferred modification of the apparatus illustrated in FIG. 1;

FIG. 5 is a view along lines 5—5 of the apparatus illustrated in FIG. 4; and

FIG. 6 is an elevation, partially in section, of a further modification of the apparatus illustrated in FIG. 1.

The sputtering and film-depositing apparatus 10 shown in FIG. 1 comprises a base 11 having a central opening 12, and a removable bell jar 14 located on base 11 and sealed thereto at an annular structure 15. A vacuum conduit 17 is connected to base 11 by a flange 18 and a weld 19. The space in base 11 and bell jar 14 is evacuated by means of a conventional high vacuum pump (not shown) which is connected to vacuum conduit 17.

The base 11 has a first lateral aperture 21 which communicates with the opening 12. A flange 22 is mounted to the base 11 at aperture 21 by a number of bolts 23. A sealing ring 25 seals the flange 22 to the base 11. A manually adjustable needle valve 26 is connected to flange 22 so that one of its ports communicates with aperture 21. The other port of needle valve 26 is connected to a pipe 27 which leads to a gas tank 28. The gas tank, which may be a gas bottle, contains an ionizable gas, such as argon, which has the effect of facilitating the ionization process in the bell jar 14, when admitted to the base 11 and jar 14 by the needle valve 26 in small quantities. It would also be possible to provide the necessary ionizing environment in bell jar 14 by adjusting the operation of the vacuum pump so as to permit a sufficient number of gas molecules to remain in the bell jar 14 during the evacuation process. However, the use of a separate gas tank and needle valve permits a more convenient and precise adjustment of the ionizing environment.

The base 11 has a second lateral aperture 31 which communicates with the space in bell jar 14 through a substantially tubular filament shield or electron guide 32 which has a bend 35. A flange 33 is fastened to the base 11 at aperture 31 by a number of bolts 34. A sealing ring 36 seals the flange 33 to the base 11. Flange 33 has an extension 38 which forms the base of a cathode member 40. The cathode member further includes a filament 41

which is supported and supplied with electric current by a pair of leads 42 that extend through the flange 33 and are insulated therefrom by a pair of insulating sleeves 44. A pair of terminals 45 is mounted on sleeves 44 and connected to leads 42. In the illustrated embodiment, the filament shield 32 carries a coil of tubing 47 which is connected to a supply of coolant liquid in a conventional manner not shown per se. The coolant liquid is caused to circulate through tubing or coil 47 so as to cool the filament shield. In this manner, overheating of the filament sheet and the release of contaminants therefrom are avoided. A baffle plate 50 encompasses the upper end of filament shield 32 and is supported by a pair of studs 51 and 52.

A bushing 54 extends through a bore 55 in flange 18 and is held therein by a nut 56. A tube 57 extends through and is sealed to the bushing 54. Tube 57 carries at its upper end an elbow member 59. A further tube 60 is connected to elbow member 59 to extend substantially perpendicularly to tube 57. An insulated wire 62 extends through tubes 57 and 60 and is connected to an anode support rod 64 at tube 60, which is insulated from tube 60, and to a terminal 65 which is mounted on the lower end of tube 57 by an insulator 66. An anode 68 is suspended from and electrically connected to support 64. Anode 68 has a substantially horizontal anode surface 70 which faces in the direction of filament shield 32.

After the base 11 and bell jar 14 have been evacuated, the filament 41 is supplied with a heating current from battery 72 which is connected to terminals 45. The anode 68 is then positively biased with respect to the filament 41 by a battery 73. The negative terminal of battery 73 is connected to one of the filament terminals 45, and may be grounded or connected to apparatus 10. The positive terminal of battery 73 is connected to anode terminal 65 through a variable resistor 75.

The heated filament 41 releases electrons to the anode surface 70. These electrons will collide with gas molecules present in bell jar 14. The gas molecules will thus be ionized and an ion plasma will form in the space between the anode and the baffle plate 50. Dotted line 130 is intended to symbolize an ion plasma 131 in a schematic manner. The ion plasma 131 extends substantially along an axis indicated by phantom line 77. The needle valve 26 may be adjusted from time to time to admit a desired quantity of gas molecules from the tank 28 to the ion plasma. Since the cathode is in the form of the heated filament 41, a large number of electrons will be released therefrom. The tubular filament shield or electron guide 32 will laterally confine these electrons and will guide them toward the ion plasma 131 in the form of an electron stream indicated by a family of dotted lines 133. The ion plasma 131 will thus continuously be provided with concentrated supplies of electrons and a vigorous formation of ion plasma will take place and be maintained as desired. The ion plasma will thus be stronger than the plasmas obtained with the same energy in those prior-art apparatus in which no electron confining and guiding structure of the type of the tubular filament shield 32 was present.

The cathode is characterized by long life, since it is not a source of sputtering material, as in prior-art apparatus, and can thus be formed of a typical cathode material that displays a high yield of electrons. The heated cathode will have a low sputtering rate because of the low voltage drops between the cathode and anode.

The particular mounting of the cathode member 40 illustrated in the drawing is highly advantageous, since the cathode can be removed from a space laterally of the base 11, so that the seal between bell jar 14 and base 11 need not be broken and the apparatus need not be moved as in some prior-art structures. In addition, the illustrated arrangement of the cathode member 40 and the filament shield 32 reduces to a minimum contamination of the space in bell jar 14 by cathode material.

A further bushing 80 extends through an aperture 81 in flange 18 and is held therein by a nut 82. A tube 84 extends through and is sealed to bushing 80. Tube 84 carries at its upper end an elbow member 85. A further tube 86 is connected to elbow member 85 to extend substantially perpendicularly to tube 84. An insulated wire 88 extends through tubes 84 and 86 and is connected to a target support 89 located adjacent and insulated from tube 86. The lower end of wire 88 is electrically connected to a terminal 90 which is insulated from tube 84 by an insulator 92.

An ion target in the form of a plate 94 is mounted on target support 89. The plate 94 is of the material to be sputtered and has a surface 95 disposed laterally of the ion plasma axis 77. In the illustrated embodiment, the surface 95 is not only spaced from axis 77 but also extends substantially parallel thereto. A substrate support 96 is mounted on and extends from baffle plate 50. A substrate 98 is mounted on and suspended from support 96. The substrate 98 has a surface 100 on which a thin film of material sputtered from target 95 is to be deposited. The surface 100 is disposed laterally of the plasma axis 77 so that it is spaced from axis 77 and faces target surface 95. In the illustrated embodiment, the substrate surface 100 extends substantially parallel to the target surface 95 and the anode surface 70 is spaced from and extends substantially at right angles to the surfaces 95 and 100.

The negative terminal of a battery 102 is connected to target terminal 90 through a variable resistor 103. The positive terminal of battery 102 is connected to the lead which extends from the positive terminal of battery 73. The target 94 and surface 95 are thus electrically biased so that positive ions from the ion plasma are caused to impinge on target surface 95. These impinging ions will sputter material from the target surface 95, which material will deposit itself on the substrate surface 100 and form a thin film thereon. During operation of the illustrated apparatus, the anode current can be adjusted by means of resistor 75 and the target current by means of resistor 103.

The apparatus further includes a substantially cylindrical cover 110 which rests on base 11 and is removable therefrom. The lateral wall of cover 110 may be of non-magnetic wire mesh. A three-leg support 111 is placed on the top of cover 110. Three chains, two of which are apparent in the drawing at 112 and 114, are suspended from support 111. A magnet structure 115 which houses an electromagnetic coil 116 is suspended from the latter chains by a number of further chains 117 which are connected to the former chains by hooks 118.

The coil 116 is energized by a battery 121 through a variable resistor 120, which permits adjustment of the current through coil 116 and thus of the magnetic field produced by this coil. The coil is of annular configuration and the magnetic field, consisting of a plurality of parallel field lines substantially parallel to target 95 and substrate 100 diagrammatically indicated in the drawing by arrows 123, extends primarily along and in the vicinity of axis 77.

In my experiments, I have discovered that the rate of deposition and thus the thickness of the film formed on substrate surface 100 can be varied at different points of the substrate surface by shifting the magnetic field produced by coil 116. The magnetic field can be selectively shifted along axis 77 toward and away from the anode 68 or anode surface 70, until a maximum uniformity of film thickness on substrate surface 100 is achieved. The occurrence of this optimum uniformity can be readily ascertained in a conventional manner by one of the well-known optical apparatus for the measurement of thin film thickness. These measuring apparatus and their use are well known in the art so that they have not been illustrated in the drawing. Shifting of the magnetic coil is easily effected in the illustrated embodiment by removing the hooks 118

from the one links of chains 112 and 114 and the third chain not visible in the drawing and by placing the hooks 118 into other links of the corresponding chains. If desired, other types of adjustable suspension, such as cable trains of variable length, may also be used to move coil 116. The magnetic field may also be easily tilted with respect to the axis 77 or the target surface 95 by placing one of the hooks 118 into a higher or lower link of the chains 112 and 114 than the other hooks. The intensity of the magnetic field may be varied by adjusting the variable resistor 120.

In one of my experiments with an apparatus of the type shown in the drawings, I have observed the formation of high-quality films of sputtered material by employing an anode to cathode voltage of 40 volts and a target voltage of -800 volts. The filament voltage was about 16 volts and the filament current about 40 amperes. The anode current was in the vicinity of 3.7 amperes and the target current about 120 milliamperes. I used argon as an ionizing gas and adjusted its pressure to about one micron. The magnetic field was produced by a coil of about 23 inches in diameter and 40 turns of No. 10 wire. The coil current was adjusted at about 14 amperes.

Most parts of the sputtering and film depositing apparatus shown in FIG. 2 are identical or closely similar to parts of the apparatus shown in FIG. 1. Like reference numerals have been employed in FIGS. 1 and 2 to designate these identical or closely similar parts.

The apparatus shown in FIG. 2 has a tubular member 150 which rests on the plate 50 and which defines a hollow space 152 that coincides with the hollow space inside the tubular shield and electron guiding member 32. The tubular member 150 which may be of a conductive or insulating material defines a nozzle 153 at the upper end thereof. The nozzle 153 defines an elongated aperture 155 which is best apparent from the view illustrated in FIG. 3. In the embodiment illustrated in FIGS. 2 and 3, the aperture 155 extends parallel to the surface 95 of the ion target 94, and also to the surface 100 of the substrate 98.

The apparatus illustrated in FIG. 2 employs an anode 157 which has a configuration that corresponds substantially to the configuration of the aperture 155. This is best apparent from FIG. 3 where an outline of the anode 157 has been shown by dotted lines. It should, in this connection, be understood that the effective area of the anode could also be made somewhat smaller than the cross-section of the nozzle aperture.

In the operation of the apparatus illustrated in FIGS. 2 and 3, the tubular shield 32 will guide electrons from the filament 41 to the inside of the tubular member 150. These electrons will move through the aperture 155 in the nozzle 153, inasmuch as they are attracted by the positively biased anode 157. A family of dotted lines 158 schematically indicates the electron flow inside the tubular members 32 and 150. In the absence of magnetic field arrows 123 the ion plasma will tend to diverge in a flat wedge-shaped configuration shown by the family of dotted lines 159. Owing to the illustrated configurations of the aperture 155 and the anode 157, the electrons issuing from the nozzle 153 will travel to the anode, in the presence of parallel magnetic field lines, arrows 123, and take the form of an electron sheet. The ion plasma established adjacent the ion target 94 will, correspondingly, have a sheet-like configuration. Ions are attracted from this sheet by the negatively biased target 95 from which they sputter material onto the substrate 98.

Owing to the sheet-like plasma configuration, the ion bombardment of the target surface 95 and the corresponding sputtering of material therefrom will be rather uniform. The result is a more uniform film deposition on the substrate surface 100. If desired, the ion target 94 and also the substrate 98 can be moved closer to the ion plasma than as illustrated in FIG. 2. It should also be understood that different types of tubular members can be employed to obtain different configurations of ion

plasmas and different sputtering effects. The expression "tubular" is used herein in a general sense, as is apparent from FIG. 3 according to which both the filament shield 32 and the member 150 are of prismatic, rather than cylindrical, configuration.

It will be recognized that the structure of the apparatus illustrated in FIGS. 2 and 3 leads to a very efficient use of the available electrons and also of the ions produced in the ion plasma. In addition, deposited films of superior uniformity or controlled thickness are obtained by locating the ion target 94 and substrate 98 parallel to each other and face-to-face at the outer surface of the flat sheet ion plasma developed by this apparatus.

The sputtering and film depositing apparatus illustrated in FIG. 4 is in many respects similar or identical to the apparatus shown in FIG. 1, so that like parts have been designated by like reference numerals.

In the embodiment shown in FIG. 4, the ion target 95 is connected to the terminal 64 which, in turn, is connected to the external terminal 65 by the above mentioned wire 62. The insulating tube 84 shown in FIG. 4 is shorter than its counterpart in the previous figures and carries a terminal rod 180. This external rod is connected by the above mentioned wire 88 to the external terminal 90. An anode 181 is mounted on the terminal rod 180. The previously described variable resistor 75 is connected to the terminal 90 so as to apply the required potential to the anode 181. The previously described bias battery 102 and adjustable resistor 103 are connected to the external terminal 65, so as to apply the required potential to the ion target 95. The tubular electron guide member 32 is somewhat longer than its counterpart in the previously described figures. However, its nature and function is still the same so that the same reference numeral has been used.

The electrons emitted by the filament 41 are guided by the tubular member 32 into the interior of an adaptor 184 which rests on the plate 50. The adaptor 184 has a nozzle 185 which extends in the direction of the anode 181. The tubular member 32 and the adaptor 184 jointly operate to provide a stream of electrons which issues through the nozzle 185 in a direction substantially parallel to the plate 50.

The configurations of the adaptor 184 and the nozzle 185 are best apparent from FIG. 5 of the drawings. From this figure it will be recognized that the nozzle 185 defines a rectangular aperture 187 which is similar to the previously described aperture 155 shown in FIG. 3. Dotted lines in FIG. 5 indicate the configuration of anode 181. This anode configuration corresponds to the configuration of the aperture 87, so that an approximately prismatic sheet of electrons and thus an approximately prismatic ion plasma will be formed between the nozzle 185 and the anode 181 in the absence of a magnetic field. Dotted lines 188 in FIG. 4 are intended to outline this ion sheet.

The potential applied to the ion target 95 in FIG. 4 causes attraction of ions from the ion plasma sheet 188. These ions sputter material from the lower surface of ion target 95. This material moves downwardly as seen in FIG. 4. A substrate 190 is located on the plate 50. A thin film of material sputtered from the target 95 is formed on the upper surface 191 of the substrate 190.

An electromagnetic coil 193 is positioned as shown in FIG. 4 to establish parallel field lines (arrows 123) and permit control of the sputtered film density on the substrate surface 191. The coil 193 is supplied with electric current by the previously described battery 121 through the adjustable resistor 120. The coil 193 may be movable as has already been described in connection with the magnet structure 115 shown in the previous figures.

The apparatus shown in FIGS. 4 and 5 has the advantage that the ion plasma sheet is in a horizontal plane, so that the substrate need not be vertically suspended. Rather, the plate 50 serves as a table for the substrate 190

which can thus easily be placed in position and removed when desired.

If desired, the apparatus of FIG. 1 can easily be dimensioned so that it can be operated in the manner shown in FIG. 2, as well as in the manner shown in FIG. 4. In this fashion, an apparatus is provided which can be operated to provide a vertical ion plasma sheet in one variation and a horizontal plasma sheet in the other variation thereof. A versatile apparatus which is adaptable to various sputtering operations can thus be constructed.

The sputtering and film depositing apparatus shown in FIG. 6 is a further development of the apparatus illustrated in FIGS. 4 and 5. The method of using like reference numerals for substantially like parts has, therefore, again been employed for the purpose of a quick and convenient reference.

The apparatus of FIG. 6 has an anode 181 which is suspended and energized in the same manner as the anode 181 in FIG. 4, except that a switch 200 is provided in the energization circuit to permit a selective individual energization and de-energization of the anode 181 in FIG. 6. The apparatus of FIG. 6 further has an anode 181' which is mounted and energized in the same manner as the anode 181 of this FIG. 6. The means for mounting and energizing the anode 181' have, therefore, been given the same reference numerals as the corresponding parts for energizing the anode 181 in FIG. 6, except that each reference numeral has been provided with a prime for better distinction.

The apparatus of FIG. 6 further includes an ion target 95 which is associated with the anode 181 and an ion target 95' which is associated with the anode 181'. The ion target 95 is of the material which is to be sputtered onto the substrate 190 located on the plate 50. The ion target 95' is of the material which is to be sputtered onto the substrate 190' located on another portion of plate 50.

The ion target 95 in FIG. 6 is energized and mounted in essentially the same manner as the like ion target 95 in FIG. 4, so that like reference numerals have been employed to indicate the parts for mounting and energizing the ion target 95 in FIG. 6. The parts for mounting and energizing the ion target 95' in FIG. 6 have also been given the same reference numerals as the like parts for mounting and energizing the ion target 95, except that a prime has been added to each reference numeral for better distinction.

It will be noted that the current source 102 shown in the previous figures is also employed in FIG. 6 where it is the common source for biasing both ion targets 95 and 95'. A switch 202 permits an individual selective energization and de-energization of the ion target 95 in FIG. 6. The ion target 95' is individually energized and de-energized by actuation of a corresponding switch 202'.

A tubular filament shield or member 32 and a tubular adaptor 205 guide electrons from the filament 41 to the general level of the anodes 181 and 181'. The adaptor 205 has a cover 206 which is spaced from the adaptor body 207 by members 208. Electrons emerging from the adaptor body 207 flow through the space between this adaptor body and the cover 206 and are attracted in the direction of anode 181 or anode 181', provided one or the other switch 200 or 200' is closed. These electrons form ion plasmas 210 or 210' as generally indicated in FIG. 6. If the switch 202 is closed, ions are attracted from the plasma 210 to the ion target 95 in FIG. 6. These ions cause the ion target to sputter and to deposit a film on the surface 191 of the substrate 190 of FIG. 6. This film deposition process may be controlled, through parallel field lines, arrows 123, in the manner mentioned above by means of a magnet coil 193 which is energized through a variable resistor 120 from a current source 121, as has already been described in connection with the apparatus of FIG. 4.

If the switch 202' is closed, ions are attracted from the plasma 210' to the ion target 95' which causes a sput-

tering of material from this ion target onto the surface 191' of the substrate 190' of FIG. 6. A magnet coil 193' which is energized through a variable resistor 120' from a battery 121' may be used to control, through parallel field lines, arrows 123, the film depositing operation onto the substrate 190'.

If desired, the switches 200 and 202 may be closed and the switches 200' and 202' may be left open so that only the sputtering system including the ion target 95 is operated. On the other hand, the switches 200 and 202 may be maintained open and the switches 200' and 202' may be closed so that only the system including the ion target 95' is operated. If desired, more anodes and ion targets and associated energizing systems can be added to the apparatus shown in FIG. 6, such as by grouping more anodes and more ion targets around the centrally located adaptor 205. Several sputtering processes can be conducted in the same vessel and can individually be started and stopped as may be desired.

Various modifications within the scope of the invention of the embodiments described and illustrated herein are apparent or will suggest themselves to those skilled in the art.

I claim:

1. A triode apparatus for depositing thin films of material on a substrate by sputtering, comprising:

- (a) an enclosure;
- (b) means for evacuating the enclosure and for providing an ionizable atmosphere in the enclosure;
- (c) means for mounting a substrate having a planar surface in the enclosure;
- (d) means for mounting an ion target having a planar surface of said material in the enclosure in a spaced parallel relationship away from and face-to-face relative to said substrate;
- (e) an anode in said enclosure;
- (f) a thermionic cathode separate and independent from said target and said substrate and housed in a chamber communicating with said enclosure by an opening which faces the space between the target and substrate for sustaining an electrical discharge and providing an ion plasma therebetween; and
- (g) electron-collimating nozzle means extending from the cathode chamber opening toward the target and substrate and including a pair of substantially flat and parallel sides lying in plans substantially parallel to the planar surfaces of the target and the substrate and extending from said cathode along said planes a sufficient distance to effect collimation of said plasma and terminating in an elongated aperture facing said space between the target and substrate for releasing a collimated sheet of electrons into said space between the target and the substrate.

2. A triode apparatus for depositing thin films of material on a substrate by sputtering from an ion target comprising.

- (a) an open-ended bell jar enclosure;
- (b) means defining a substantially horizontal base for sealing said enclosure and for supporting said target and said substrate;
- (c) means for evacuating the enclosure and for providing an ionizable atmosphere in the enclosure;
- (d) means for mounting in the enclosure a substrate having a flat surface in a position facing and parallel to a predetermined axis in the enclosure;
- (e) means for mounting in the enclosure an ion target having a flat surface of said material to be sputtered in a parallel position spaced away from and face-to-face relative to said substrate surface and to said predetermined axis;
- (f) an anode in said enclosure;
- (g) a thermionic cathode separate and independent from said target to said substrate and housed in a chamber communicating with said enclosure by an opening in said base centered on said predetermined

axis and facing the space between the target and substrate for sustaining an electrical discharge and providing an ion plasma therebetween; and

- (h) electron-collimating nozzle means extending from the cathode chamber opening in the base toward the target and substrate and including a pair of substantially flat and parallel sides lying in planes substantially parallel to the planar surfaces of the target and the substrate and extending from said cathode along said planes a sufficient distance to effect collimation of said plasma and terminating in an elongated aperture centered on said predetermined axis and facing said space between the target and substrate for releasing a collimated sheet of electrons into said space between the target and the substrate.

3. A triode apparatus in accordance with claim 2 wherein said cathode chamber includes at least one bend defining a chamber portion for housing said thermionic cathode at an angle intersecting said predetermined axis and operative for shielding the substrate and the target from contamination by material emitted from the cathode.

4. Apparatus for depositing thin films of material on a substrate by sputtering comprising:

- (a) an enclosure;
- (b) means for evacuating the enclosure and for providing an ionizable atmosphere in the enclosure;
- (c) means for mounting a substrate having a flat surface in the enclosure;
- (d) means for mounting an ion target having a flat surface of said material in the enclosure in a spaced parallel relationship away from and face-to-face relative to said substrate;
- (e) means including an electron-releasing cathode in a sealed housing with an opening communicating with said enclosure for establishing an ion plasma adjacent said ion target to sputter material from said ion target for the formation of films on said substrate;
- (f) shield means extending from the opening of the cathode housing toward the region in which said ion plasma is formed to guide electrons released by the cathode to the ion plasma, said shield means including a pair of elongated substantially flat and parallel sides lying in planes substantially parallel to the flat surfaces of the target and the substrate and extending from said cathode along said planes a sufficient distance to effect collimation of said plasma to define an elongated aperture located in the enclosure and facing the space between the target and the substrate for releasing the electrons to said region substantially in the form of an electron sheet; and
- (g) means for confining said ion plasma in a sheet-like form having opposed flat boundaries substantially parallel to and sandwiched between the face-to-face flat target and substrate surfaces.

5. A triode apparatus for depositing thin films of material on a substrate by sputtering, comprising:

- (a) an enclosure;
- (b) means for evacuating the enclosure and for providing an ionizable atmosphere in the enclosure;
- (c) means for mounting a substrate having a flat surface in the enclosure;
- (d) means for mounting an ion target having a flat surface of said material in the enclosure in a spaced parallel relationship away from and face-to-face relative to said substrate;
- (e) an anode in said enclosure;
- (f) a thermionic cathode separate and independent from said target and said substrate and housed in a chamber communicating with said enclosure by an opening therein; and
- (g) electron-collimating nozzle means extending from

the cathode chamber opening into said enclosure and terminating in at least one elongated aperture facing the space between the target and substrate for releasing a collimated sheet of electrons into said space between the target and the substrate, said elongated aperture including a pair of substantially flat and parallel sides lying in planes substantially parallel to the flat surfaces of the target and the substrate and extending from said cathode along said planes a sufficient distance to effect collimation of said plasma.

6. Apparatus in accordance with claim 5 and further comprising:

- (a) base means defining in said enclosure a substantially horizontal mounting surface sealing said enclosure, said base including said cathode chamber opening therein;
- (b) means coupling said cathode chamber to a lower surface of said base at said chamber opening; and
- (c) means coupling said nozzle means to the upper surface of said base at said chamber opening.

7. Apparatus in accordance with claim 6 wherein:

- (a) said cathode housing chamber includes at least one bend defining a first chamber portion substantially horizontal with said base for housing said thermionic cathode; and
- (b) said bend further defining a second chamber portion for guiding electrons emitted by said cathode to said chamber opening in said base.

8. Apparatus in accordance with claim 7 wherein:

- (a) said mounting means includes mounts positioning said flat target and said flat substrate surfaces substantially horizontal relative to said base and in spaced, parallel, and face-to-face relationship with each other.

9. Apparatus in accordance with claim 8 wherein:

- (a) said nozzle means includes at least one bend defining a first elongated nozzle portion substantially horizontal with said base and forming said terminating elongated aperture by a pair of elongated flat and parallel sides lying in planes substantially parallel to the flat surfaces of the target and the substrate; and
- (b) said bend further defining a second nozzle portion vertically positioned above said cathode chamber opening.

10. Apparatus in accordance with claim 8 and further comprising:

- (a) a pair of flat substrate surfaces and a pair of flat target surfaces, one each of said target pair being parallelly spaced from and face-to-face with one each of said substrate pair, and having a sheet-like ion plasma sandwiched therebetween; and
- (b) a pair of elongated apertures in said nozzle means, one each of said apertures facing the space between the target and substrate for releasing a collimated sheet of electrons into one each of the spaces between the target and the substrate, each of said elongated apertures including a pair of substantially flat and parallel sides lying in planes substantially parallel to the flat surfaces of the target and the substrate.

11. Apparatus in accordance with claim 10 wherein:

- (a) said nozzle means extending into said enclosure comprises a vertical tube positioned between said target and substrate pairs, said vertical tube including an end cap adjacent said pair of elongated apertures.

12. Apparatus in accordance with claim 11 wherein:

- (a) said cathode housing chamber includes at least one bend defining a first chamber portion substantially horizontal with said base for housing said thermionic cathode; and
- (b) said bend further defining a second chamber portion for guiding electrons emitted by said cathode to said chamber opening in said base.

13. Apparatus for depositing thin films of material on a surface of a substrate by sputtering, comprising:

- (a) an enclosure having a base and a vessel sealably and removably mounted on said base, said base having a central opening communicating with said vessel and a lateral aperture communicating with said central opening;
- (b) means for evacuating said vessel and for selectively admitting an ionizable gas to said vessel;
- (c) means for establishing in said vessel an ion plasma extending substantially along a predetermined axis at right angles to said base, said means for establishing said ion plasma including an anode located in said vessel and above said base and having an anode surface extending substantially parallel to said base, and an electrically heated cathode filament removably sealed in said lateral aperture and operative to emit electrons into said central opening;
- (d) an ion target of said material located in said vessel and having a surface facing and laterally spaced from said ion plasma axis generally parallel thereto and located between said anode and said base;
- (e) means for electrically biasing said target to cause impingement of ions from said plasma on said target;
- (f) means for mounting said substrate in said vessel with said surface of the substrate facing and being laterally spaced from said ion plasma axis to be substantially parallel to and facing said surface of the target; and
- (g) means for establishing in said enclosure in the absence of an ion plasma along said axis, a magnetic field having longitudinal and unidirectional field lines through the space between said substrate and said target and substantially parallel to said predetermined axis.

14. Apparatus for depositing thin films of sputtered material in accordance with claim 13 wherein:

- (a) said ion target and said substrate surface are of planar configurations;
- (b) said central opening faces into said vessel and comprises
 - (1) an elongated slot having the longest dimensions thereof lying in planes substantially parallel to the parallel faces of said target and said substrate for directing electrons emitted by said cathode as a substantially sheet-like beam into the space between said substrate and said target, and
- (c) said magnetic field establishing means sandwiches said ion plasma as a substantially sheet-like form between said target and said substrate surfaces.

15. Apparatus for depositing thin films of material on a surface of a substrate by sputtering, comprising:

- (a) a substantially vertical vacuum enclosure including means defining a lateral aperture;
- (b) means for evacuating said enclosure and for selectively admitting an ionizable gas to said enclosure;
- (c) a cathode member including a base sealably mounted in said enclosure, elongated cathode supports extending substantially horizontally to said base, and an electron-releasing cathode filament mounted on said supports;
- (d) an anode spaced from said cathode member and having a substantially horizontal anode surface;
- (e) means for supplying a heating current to the cathode filament and a positive electric potential to the anode with respect to the cathode to establish in said enclosure an ion plasma extending substantially along a predetermined axis;
- (f) a target of said material mounted in said enclosure laterally of said plasma axis, said target having a substantially vertical target surface;
- (g) means for electrically biasing said target to cause

ions from said plasma to impinge on the target surface;

- (h) means for mounting said substrate in said enclosure laterally of said plasma axis, with said surface of the substrate facing said target surface;
- (i) means for establishing in said enclosure a magnetic field extending substantially along parts of said plasma axis; and
- (j) means for selectively shifting said magnetic field along said plasma axis.

16. Apparatus for depositing thin films by sputtering in accordance with claim 15 wherein

- (a) said target and said substrate surfaces are planar,
- (b) said lateral aperture houses said cathode filament and comprises a tubular shield means for guiding electrons from said lateral aperture into said enclosure substantially along said predetermined axis, and
- (c) a nozzle coupled to said tubular shield with an aperture substantially centered on said predetermined axis and having elongated parallel sides lying in planes substantially parallel with the planar target and substrate surfaces.

17. A triode apparatus for depositing thin films of material on a surface of substrate by sputtering comprising:

- (a) a vessel enclosure having an opening therein sealably closed by a cathode mounting member;
- (b) means for evacuating said vessel and providing an ionizable atmosphere therein;
- (c) means for establishing in said vessel an ion plasma extending along a predetermined axis substantially at a right angle to said cathode mounting member, said plasma establishing means comprising an anode remotely located in said vessel from said member, an electrically heated cathode filament mounted on said member for emitting electrons, shield means positioned between said anode and said filament and having a substantially elongated aperture for establishing a substantially sheet-like ion plasma along said predetermined axis;
- (d) a planar ion target of said material located in said vessel and having a surface facing and laterally spaced from said ion plasma axis generally parallel thereto and located between said anode and said shield;
- (e) means for electrically biasing said target to cause impingement of ions from said plasma to said target;
- (f) a planar substrate mounted in said vessel with said surface of the substrate facing and being laterally spaced from said ion plasma axis to be substantially parallel to and face said surface of the target; and
- (g) means for establishing in said enclosure in the absence of an ion plasma along said axis, a magnetic field having longitudinal and unidirectional field lines through the space between said substrate and said target and substantially parallel to said predetermined axis.

18. Apparatus for depositing thin films of material on a surface of a substrate by sputtering, comprising

- (a) an enclosure;
- (b) means for evacuating said enclosure and providing an ionizable atmosphere therein;
- (c) an ion target of said material in said enclosure;
- (d) means for mounting said substrate in the enclosure with said surface of the substrate extending substantially parallel to, being spaced from and facing, a surface of the target;
- (e) means in said enclosure including an anode and a thermionic cathode and an elongated aperture positioned between the cathode and the anode for sustaining an electrical discharge of substantially sheet-like form between, and generally axially parallel to, the surface of the target and the substrate, said

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anode and said cathode being separate and independent from said substrate and said target;

(f) means for applying to said anode positive electric potential with respect to said cathode for forming ion plasma of random ionization having a rectangular cross-section and normally tending to diverge into a wedge shape between said cathode and said anode;

(g) means for selectively establishing in said enclosure, at least during the absence of an ion plasma therein, a magnetic field having longitudinal field lines substantially parallel to the parallel surfaces of said substrate and said ion target, said field lines being unidirectional through the space between said substrate and said target for reshaping the divergent ion plasma to a controlled plasma of substantially uniform ionization having a sheet-like form in the space between the substrate surface and the ion target surface; and

(h) means for applying a negative potential to said target to cause attraction of ions to said target.

19. Apparatus for depositing thin films of material on the surface of a substrate by sputtering in accordance with claim 18 wherein

(a) said ion target is of a planar configuration, and

(b) said substrate is of a planar configuration.

20. Apparatus for depositing thin films of material

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on the surface of a substrate by sputtering in accordance with claim 19 and further comprising

(a) means for mounting said ion target with its planar surface substantially at the outer boundary of said sheet-like ion plasma, and

(b) means for mounting said substrate with its planar surface substantially at the opposed outer boundary of said sheet-like ion plasma.

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ROBERT K. MIHALEK, *Primary Examiner.*

JOHN H. MACK, HOWARD S. WILLIAMS,

Examiners.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,393,142

July 16, 1968

Roger M. Moseson

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 51, "reduces" should read -- reduce --.
Column 6, line 23, "external" should read -- terminal --.
Column 8, line 46, "plans" should read -- planes --.

Signed and sealed this 30th day of December 1969.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents