Dec. 30, 1969 D. G. HAJZAK 3,487,000

SPUTTERING APPARATUS

Filed Feb. 27, 1967 3 Sheets-Sheet 1

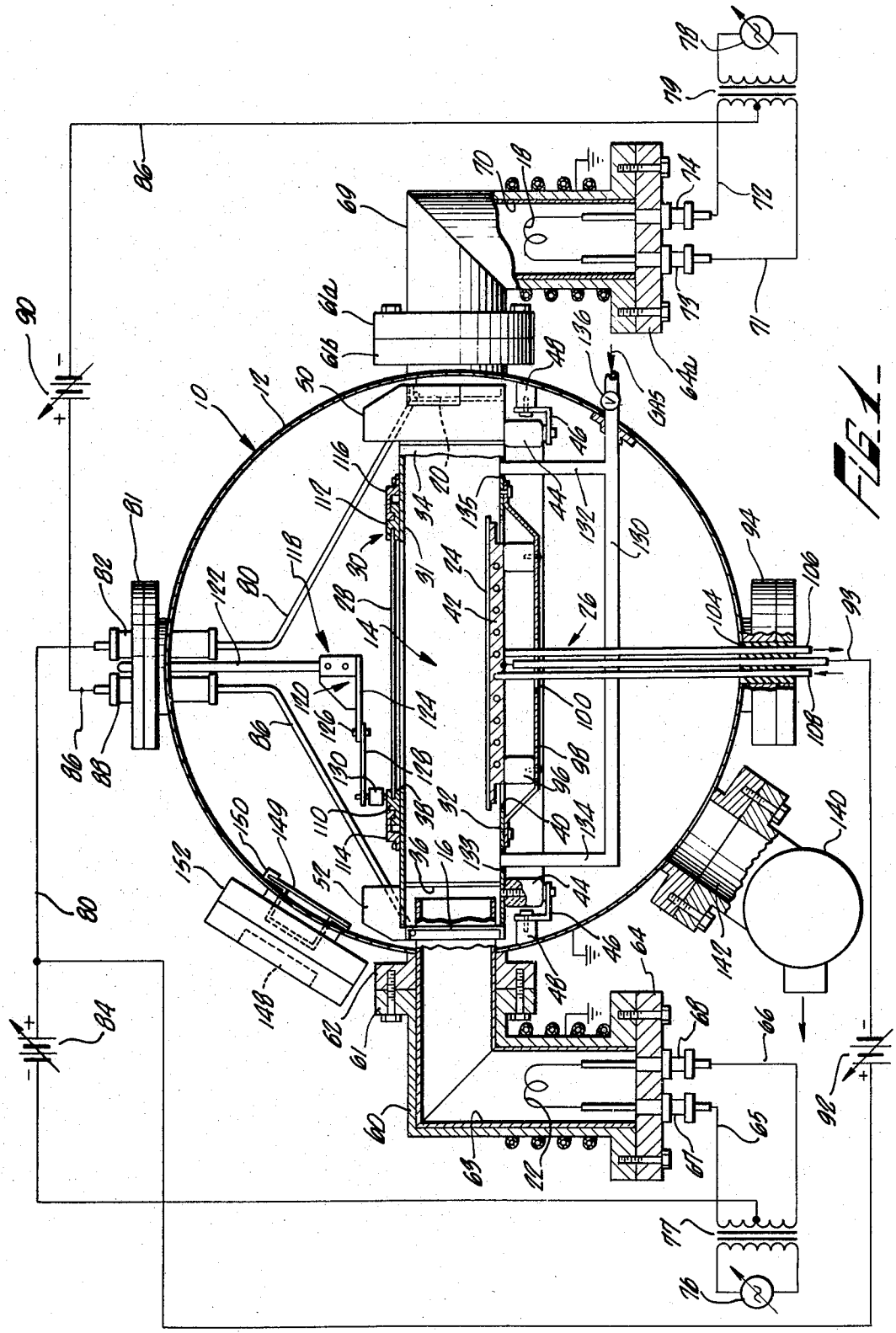

FIG 1

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SPUTTERING APPARATUS

Filed Feb. 27, 1967 3 Sheets-Sheet 2

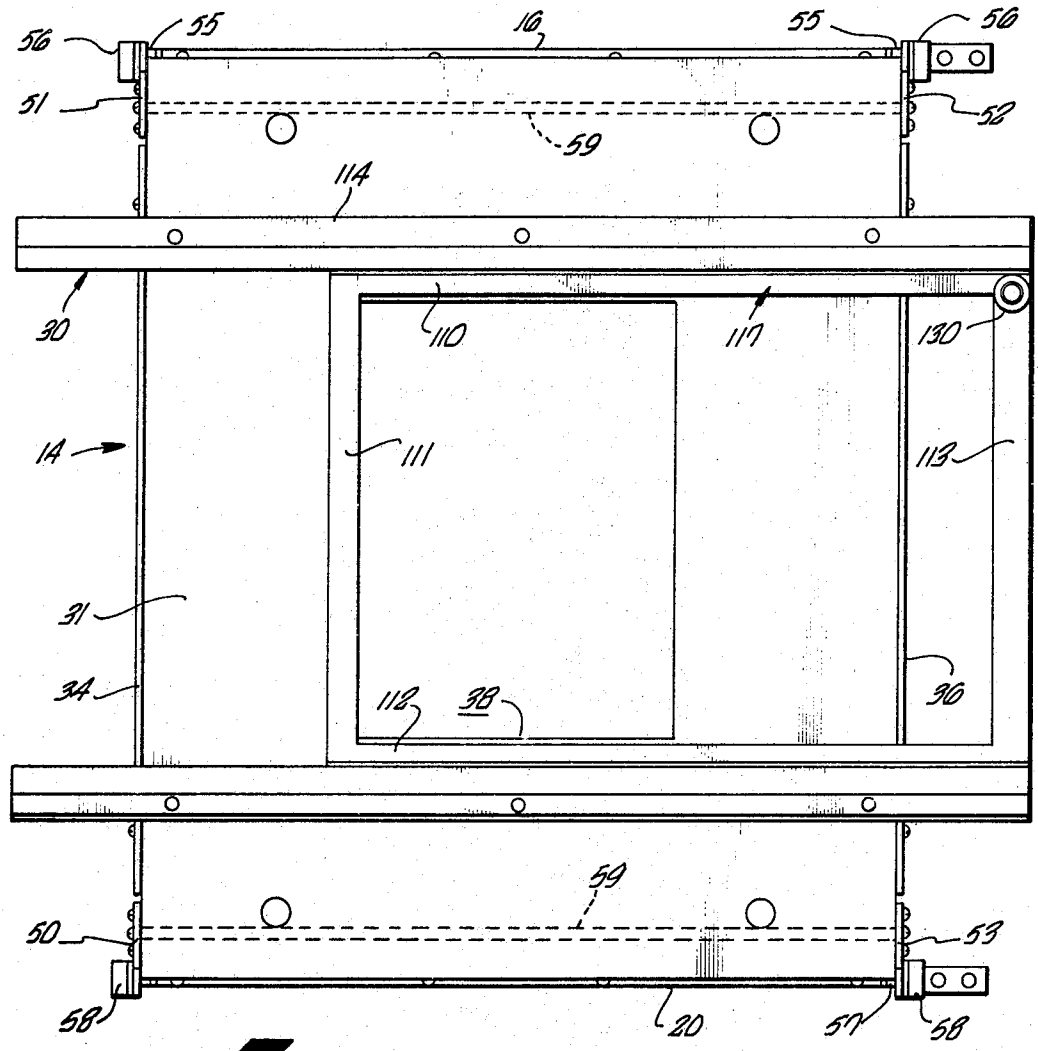

FIG. 3.

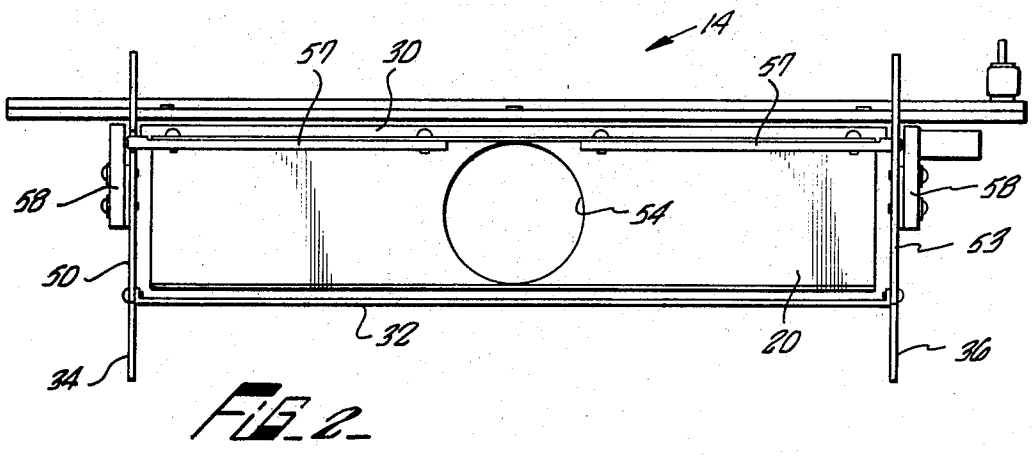

FIG. 2.

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SPUTTERING APPARATUS

Filed Feb. 27, 1967 3 Sheets-Sheet 3

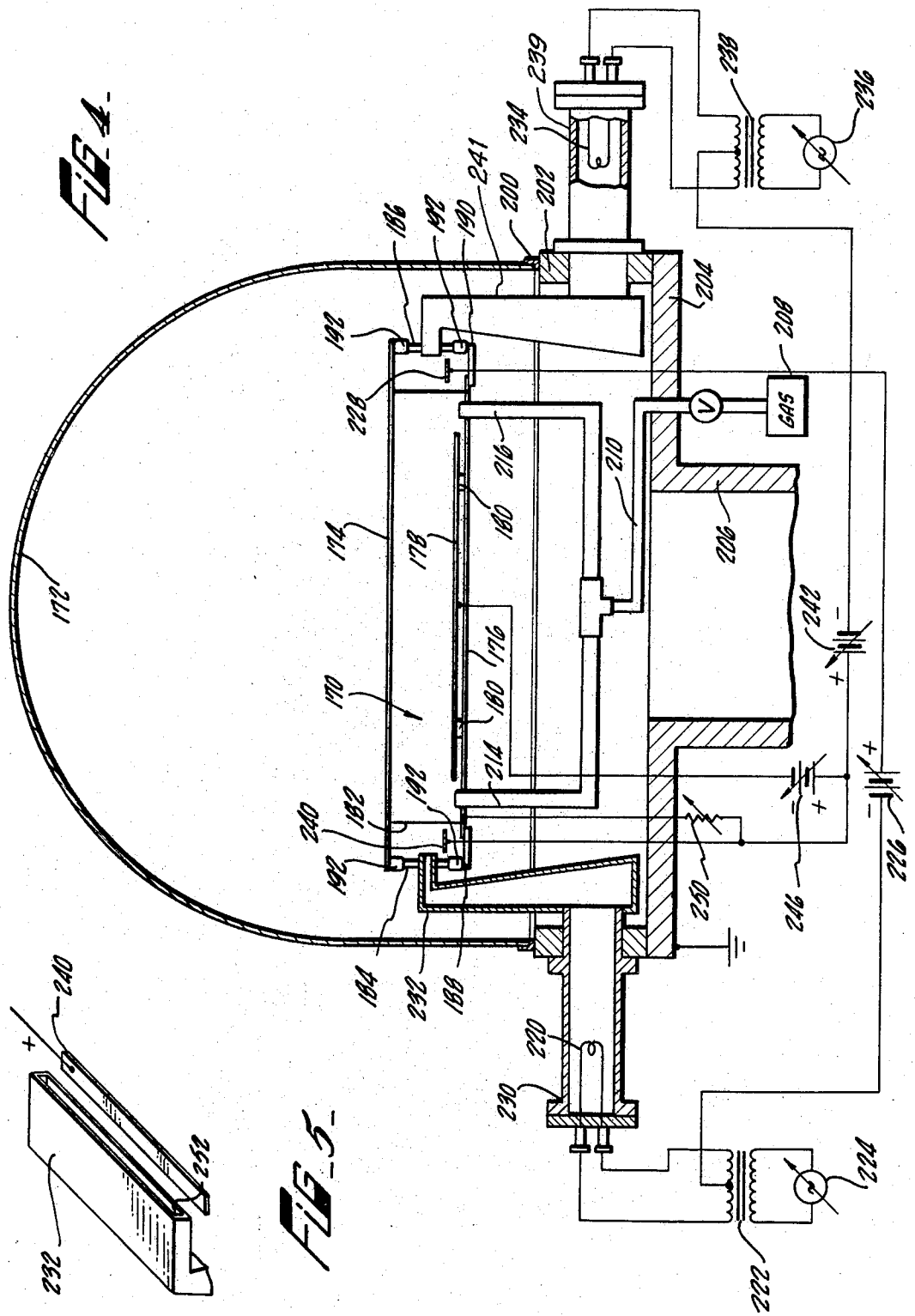

FIG. 4.

FIG. 5.

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3,487,000

SPUTTERING APPARATUS

Dennis G. Hajzak, Rochester, N.Y., assignor, by mesne assignments, to The Bendix Corporation, Detroit, Mich,, a corporation of Delaware

Filed Feb. 27, 1967, Ser. No. 618,644
Int. Cl. C23c *15/00*
U.S. Cl. 204—298 8 Claims

ABSTRACT OF THE DISCLOSURE

An ion-plasma confining enclosure, disposed within a larger enclosure, is used to increase ion intensity and uniformity over an ion target. The inner or plasma confining enclosure has two spaced-apart, parallel plates for the confinement of the ion plasma into a rectangular slab or sheet over the ion target. The enclosure also includes two confining side members to prevent plasma from escaping into the larger enclosure. The confinement of the plasma is produced by maintaining a positive charge on the confining enclosure of sufficient strength to repel incident ions from the plasma. The requisite positive charge results by electrically floating the plasma confining enclosure or, alternately, by biasing the enclosure slightly positive with respect to the mean plasma potential. Double opposing cathode and anode pairs are used to establish an ion plasma and to augment the confining enclosure in improving ion intensity and uniformity over the ion target.

BACKGROUND OF THE INVENTION

This invention relates to the art of sputtering and, more in particular, to a sputtering apparatus which improves ion concentration and uniformity.

It is well known that sputtering of an ion target with ions to generate atoms or molecules of material produces extremely dense and coherent films on a substrate mounted in position to receive the sputtered material. Ideally, these sputtered films are of uniform thickness and are produced at a reasonably rapid rate. The rate of film deposit is a function of the sputtering rate of the target while uniformity of film thickness is a function of the uniformity of ion bombardment of the target. A considerable amount of effort is presently being devoted to enhancing film deposition rates and thickness uniformity. It is to the enhancement of film deposition rates and uniformity of film thickness that this invention is directed.

SUMMARY OF THE INVENTION

The instant invention provides an improved sputtering apparatus which presents a relatively intense and uniform concentration of ions for the bombardment of an ion target, thereby producing uniform films on an appropriately mounted substrate as well as increased sputtering rates.

In one form, the invention contemplates an ion-plasma confining enclosure which includes first and second spaced-apart and parallel inner surfaces that form two of the inner boundaries of the enclosure. Preferably, the remaining boundaries are provided by two side plates which together with the parallel inner surfaces define a rectangular, box-like inner periphery for the ion plasma. Means are provided to evacuate the confining enclosure. The apparatus also includes means for establishing and maintaining an ionizable atmosphere within the ion-plasma confining enclosure; these means may include, for example, a source of gas together with a valve for selectively admitting the gas to the enclosure. Means are also provided for establishing an ion plasma within the confining enclosure, such as an anode and cathode. Means

for mounting an ion target within the enclosure parallel to the first inner surface as well as for mounting a substrate parallel to and facing the target to receive sputtered material are also included. The means for mounting the substrate may be, for example, the enclosure adapted with a window over which the substrate can be positioned. Alternatively, the substrate may form a part of the enclosure or be mounted on a bracket or stand. In addition, means are provided for maintaining a positive charge on the enclosure which is sufficient in magnitude to confine the ion plasma, by repulsing ions, into a sheet-like form between the enclosure's inner surfaces. The plasma confining charge may be established by electrically floating the confining enclosure. An electrically floating state is achieved when the confining enclosure is electrically isolated from charge draining structure and accepts a positive charge from the ion plasma. The magnitude of the charge will increase until an equilibrium condition exists between the enclosure and the ion plasma. In general, equilibrium is established when the plasma confining enclosure is at a potential positive with respect to the system's cathode but slightly less than anode potential. Alternately, the repelling charge may be established by positively biasing the confining enclosure with an independent, positive potential source, preferably to a potential approaching that of the anode but slightly greater than mean plasma potential. The accumulated positive charge is limited to effect substantially plasma potential on the confining enclosure to prevent electron drain from the plasma.

The ion-plasma confining enclosure, through its positive charge, produces a sheet- or slab-like plasma defined approximately by the inner geometry of the enclosure. In the sense used here, the sheet-like plasma has a thickness limited by the spacing between the upper and lower confining members. As is seen from the drawings, which depict relative dimensions of two preferred embodiments, the distance between the upper and lower confining members may be relatively large with respect to the length and breadth dimensions of the confining enclosure. The plasma is relatively uniform and dense over the surface of an ion target disposed within the limits of the enclosure parallel to its inner surfaces; therefore, rapid and uniform sputtering rates over the entire target surface are possible.

To augment the uniformity and increased plasma density produced by the plasma confining enclosure's positive charge, a preferred embodiment of the invention employs at least two cathode-anode pairs disposed to create a double opposed discharge within the enclosure. The double opposed discharge is produced by having the first cathode-anode pair create an electron attracting field acting in one direction within the confining enclosure while the second pair produces a field which attracts electrons emitted from its cathode in a direction opposite from that produced by the first pair. The anode-cathode pairs have independent power supplies to effect these opposed fields. The ion target is then disposed in the center of the plasma developed by the double opposed discharge in order to feel its maximum effect.

Enhancement of ion uniformity over the target is produced in one embodiment of the invention by an electron deflector or shaping means which has a slit-like opening that emits electrons as a sheet into the rectangular, box-like plasma confining enclosure. These deflectors are preferably used with the anode-cathode pairs described. The enclosure's positive electric charge still confines the ion plasma but cooperates with the slit-like openings and double discharge to increase its uniformity over the target.

It has been found, however, that good sputtering rates with uniform coatings can be produced without the slit-like electron deflectors. In this instance, electrons may be

admitted into the rectangular, box-like enclosure through a standard cylindrical cathode shield. In short, the confining affect of the positive electric charge associated with the enclosure produces a sheet-like plasma with its concomitant high ion density and uniformity.

The plasma confining enclosure is ideally suited for mounting the substrate. The substrate can form a part of the enclosure or it may be structurally independent. By providing an outer gas-tight enclosure for housing the plasma confining enclosure, a window may be provided in one of the plasma confining or inner enclosure's members over which a substrate can be mounted. The substrate's removal and positioning from outside the outer enclosure is then readily accomplished. Removal and positioning of the substrate is preferably provided by a frame in which the substrate can be mounted. The frame is held in position by a pair of guides disposed on one of the inner enclosure's plasma confining members. The frame can be slid in the guides for the positioning of the substrate over the window. Linkage connecting the frame to outside the outer enclosure provides for substrate positioning without disturbing the vacuum environment. Such a linkage may be, for example, a rotatable shaft which extends through the outer enclosure and which is connected to a crank which in turn is connected to the frame. The ion target is preferably positioned opposite and parallel to the substrate. A target mount electrically isolated from the enclosure may be used to support the target within the enclosure a small distance from its bottom member. The spacing insures the immersion of the target in the sheet-like ion plasma and reduces sputtering from behind the target which would otherwise waste power.

To avoid the sputtering of undesirable material it is preferred to shield structural components of the sputtering apparatus from the ion plasma. The plasma confining enclosure itself, through its associated positive charge, is shielded from ion bombardment. Such items as electron deflectors and feed-through collars are normally grounded and therefore should be shielded to avoid their sputtering. Once again, the plasma confining enclosure serves as a shield against the sputtering of structure outside the enclosure and within an outer enclosure because of its confining influence on the ion plasma. Cathode shields or electron deflectors, which are normally exposed to the plasma despite the plasma confining enclosure, may be lined with a ceramic material to prevent the sputtering of its metallic structure. The anodes may serve as a barrier against ion escape from the ends of the enclosure or, alternatively, a shield may be used which is allowed to electrically float and develop its own repulsive positive charge.

The sputtering apparatus of this invention is ideally suited for the formation of uniform sputtered films on a substrate at a relatively rapid rate. The plasma confining enclosure intensifies the plasma and renders its ion intensity more uniform over the ion target by forming the plasma into a sheet and preventing its escape into an outer enclosure if such is used. The use of a double opposed discharge increases ion density and uniformity over the target. Uniformity is enhanced because the discharges emanating opposite directions overlap and reduce areas of low ion intensity. The use of an electron deflector with a slit-like opening in cooperation with the confining positive charge of the enclosure also increases the plasma uniformity because of its tendency to enhance the sheet-like plasma.

These and other features, aspects and advantages will become more apparent from the following description, appended claims and drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIGURE 1 is an elevational view, partly in half section, of a preferred embodiment of the present invention which includes a side elevation of a preferred plasma confining enclosure;

FIGURE 2 is an end elevational view of the plasma confining enclosure shown in FIGURE 1;

FIGURE 3 is a plan view of the plasma confining enclosure shown in FIGURES 1 and 2;

FIGURE 4 is an elevational schematic, partly in half section, of an alternate embodiment of the present invention; and

FIGURE 5 is a fragmentry, perspective view of one of the electron deflectors and anodes shown in FIGURE 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGURE 1 shows a preferred embodiment **10** of the sputtering apparatus of the present invention. In general, the apparatus includes an outer cylindrical enclosure **12** in the form of a vacuum chamber which contains an inner, plasma confining enclosure **14**. An ion plasma is generated within ion-plasma confining enclosure **14** by two pairs of independently powered cathodes and anodes. The first cathode-anode pair consists of anode **16** and cathode **18** which are electrically coupled to a power source. The second pair includes anode **20**, shown in phantom, and cathode **22** which are coupled to an independent power source. Target **24** is mounted within inner enclosure **14** on target support assembly **26**. Subtrate **28** is mounted for the receipt of sputtered material from target **24** in substrate mounting assembly **30**.

Plasma confining inner enclosure **14** is depicted in the first three figures. The inner enclosure is a box-like structure which defines an interior that confines an ion plasma into a sheet or rectangular slab. Upper plate **31** and parallel bottom plate **32** form two of the confining members of inner enclosure **14**. The confining portions of the enclosure are completed by the two parallel side members **34** and **36**. Plate **31** has a centrally disposed rectangular aperture **38** which forms a window for the passage of sputtered material from target **24** for the formation of a film on substrate **28** (the target and substrate are shown in FIGURE 1). Bottom plate **32** also has a centrally disposed, rectangular aperture **40** for the mounting of target **24** on target support **42** above the inner surface of plate **32**. Enclosure **14** is electrically insulated from outer enclosure **12** in order to maintain it in an electrically floating state. This state is achieved when the members which define enclosure **14** accept and retain a positive charge from the ion plasma. The resultant potential of these members approaches anode potential and is therefore positive with respect to the system's electron emitting sources, that is, cathodes **18** and **22**. The positive charge repulses positive ions from the plasma thereby confining the plasma within enclosure **14**. In the embodiment shown in FIGURE 1, an electrically floating state is achieved by mounting enclosure **14** in outer enclosure **12** through insulators. Thus, bottom plate **32** is connected to insulators **44** which in turn are mounted on brackets **46**. Brackets **46** are secured to the inner wall of enclosure **12** through studs **48**. The support provided through insulators **44** forms the only connection of enclosure **14** to grounded outer enclosure **12**, the remaining parts of the enclosure being supported by bottom plate **32**. Thus, brackets **50** through **53** are connected to bottom plate **32** with upper plate **31** connected to these brackets. Side plates **34** and **36** are, in turn, supported by upper plate **31**.

Anodes **16** and **20** are mounted to face the axis of the ion plasma contained in inner enclosure **14**. Each anode has a centrally disposed, cylindrical opening for the passage of electrons into the ion plasma from the apparatus' electron sources. Thus, opening **54** in anode **20** provides egress for electrons emitted from cathode **18**. Each anode is electrically insulated from its supporting enclosure. Anode **16** is connected to support rods **55** which pass through, but out of electrical contact with, brackets **51** and **52** for receipt by insulator mounts **56**. Similarly, anode **20** is held in place by support rods **57**

which extend through brackets **50** and **53** for support in insulator mounts **58**. The passage of rods **57** through brackets **50** and **53** is such as to avoid electrical contact. Insulator mounts **56** and **58** are secured to their associated brackets. Braces **59** between brackets **51** and **52** and brackets **50** and **53** are provided to increase the inner enclosure's strength.

Cathode **22**, in the form of a wire filament, is contained in water cooled cathode housing or shield **60**. The shield has a mounting flange **61** for connection to flange **62** on outer enclosure **12**. The inside of shield **60** is bounded by a ceramic liner **63**. Liner **63** extends through anode **16** and partially into the volume defined between plates **31** and **32**. The ceramic liner reduces the impact of ions on the inside of the metallic body of filament shield **60** thereby diminishing the emanation of contaminants. Shield **60** is capped by closing plate **64**. Power is supplied to filament **22** through leads **65** and **66** which pass through insulating sleeves **67** and **68**. Cathodic filament **18** is also mounted in a water cooled shield which is denoted by reference numeral **69**. Shield **69** is mounted to enclosure **12** through mounting flanges **61***a* and **61***b* and is capped by closing piece **64***a*. Ceramic liner **70** is disposed within shield **69** to avoid shield sputtering. Liner **70** extends through anode **20** for electron communication with the interior of enclosure **14**. Leads **71** and **72** extend through sleeves **73** and **74** to provide current for filament **18**. Power is supplied to cathode **22** by variable alternating current power source **76**. Transformer **77** has its primary windings coupled to power source **76**. The secondary windings of transformer **77** are connected to leads **65** and **66** for the supply of current to cathode **22**. Variable alternating current source **78** is coupled through transformer **79** to filament **18**. The coupling is through the secondary windings of transformer **79** which are connected to leads **71** and **72**. Anode **20** is coupled through lead **80** to the secondary winding of transformer **77**. Lead **80** extends through mating flanges **81**, on outer enclosure **12**, through insulating sleeve **82**. Variable anode power source **84** is connected between anode **20** and the secondary winding of transformer **77** such that anode **20** is positive with respect to cathode **22**. Anode **16** is connected to lead **86** which passes through sleeve **88** for connection to variable anode power source **90**. Power source **90** is connected to the secondary winding of transformer **79** to maintain anode **16** positive with respect to cathode **18**. As was previously mentioned, anode **16** and cathode **18** are electrically independent from cathode **22** and anode **20**. These independent cathode-anode pairs create two distinct fields of force acting in opposite directions within enclosure **14** which enhances plasma density and uniformity over target **24** and thus the rate of deposition and the uniformity of sputtered coatings on substrate **28**. Target support **42** is electrically coupled through target power supply **92** to the positive terminal of anode power supply **84** by lead **93**. Lead **93** extends through mating flanges **94** on outer enclosure **12** for its connection to target support **42**. Target power supply **92** is coupled in circuit such that target support **42** is negative with respect to the ion plasma in enclosure **14** for the attraction of its ions.

Target support assembly **26** comprises target support **42** which is mounted through insulators **96** to recessed bracket **98**. Bracket **98** in turn is connected to plate **32**. Insulators **96** maintain the electrically floating condition of inner enclosure **14** and the proper bias on target support **42**. Bracket **98** has a centrally disposed aperture **100** which receives cooling lines **106** and **108** that continue as a coil in target support **42** for the latter's cooling. Electrical lead **93** may be connected directly to the cooling lines as opposed to the direct connection to target support **42** illustrated. Because lines **106** and **108** are at target potential, they are insulated from remaining portions of the sputtering apparatus **10** by insulator **104**.

Plasma confining member **31** has a window **38** over which substrate **28** is mounted. Substrate **28** faces and is parallel to target **24** in order to achieve uniform film thickness. As seen in FIGURES 2 and 3, substrate **28** is mounted in substrate mounting assembly **30** in the latter's frame members **110** and **112** which together with frame members **111** and **113** constitute a slidable frame **117**. Frame **117** is capable of sliding transversely on plate **31** for the positioning of substrate **28** over window **38**. To this end, guides **114** and **116** slidably engage frame members **110** and **112**. The substrate mounting assembly allows substrate **28** to be positioned from outside enclosure **12**. This is shown in FIGURE 1 and is accomplished through control arm assembly **118** which consists of a crank **120** and a rotary shaft **122**. Crank **120** has an arm **124** which is fixed to shaft **122**. Arm **124** is connected through pivot pin **126** to following arm **128**. Pivotable arm **128** is connected to the frame **117** of substrate mounting assembly **30** through insulator **130**. Rotation of shaft **122**, then, can be converted to translational movement of substrate **28** because of arm **128**'s connection to the slidable portion of the substrate's mount, frame **117**.

An ionizable atmosphere is supplied to enclosure **14** through gas supply line **130**. Line **130** branches into two gas lines **132** and **134** which open into enclosure **14** between target **24** and anodes **16** and **20**. Gas is admitted to lines **132** and **134** through valve **136**. Valve **136** is connected to a source of ionizable gas such as argon (not shown). To maintain the electrically floating state of enclosure **14**, lines **132** and **134** are insulated from plate **32** by insulating grommets **133** and **135**.

As is usual in sputtering apparatus, means are provided for evacuating the enclosure in which an ion plasma is to be established. For this purpose, evacuation pump **140** is conected through duct **142** to the interior of enclosure **12** and hence the interior of plasma confining enclosure **14**. Pump **140** is shown schematically, for it may take the form of any of a number of prior art pumpdown systems, such as a forepump and a getter ion pump.

Sight glass **148** is provided to allow observation of the sputtering process. Glass shield **149** is mounted in brackets **150** to protect the sight glass. Mating flanges **152** on enclosure **12** support sight glass **148** and shield **149**.

FIGURES 4 and 5 depict an alternate embodiment of the present invention. This embodiment employs electron deflectors to cooperate with the plasma confining enclosure in the production of a sheet-like ion plasma within this inner enclosure. It also shows an alternate mode for maintaining an ion-plasma confining positive charge within the inner enclosure. Inner enclosure **170**, rectangular and box-like in form, is contained within bell jar **172**. Enclosure **170** has an upper, horizontal, plasma confining member **174**. In this embodiment, member **174** constitutes the substrate upon which a sputtered film can be deposited. Bottom plasma confining plate **176** is parallel to substrate **174** and supports target **178** through insulators **180**. Side plate **182**, as well as a complementary side plate which is not shown, are disposed in parallel relation to each other outside of substrate **174**. Thus, enclosure **170** has four sides for the confinement of an ion plasma. Standoff insulators **184** and **186**, disposed at either end of the enclosure, support substrate **174** and, through brackets **188** and **190**, bottom plate **176**. These insulators are shielded from sputtered material by shields **192**.

The outer enclosure, in the form of a bell jar **172**, is mounted through seal **200** on feed-through collar **202**. Feed-through collar **202** is annularly disposed on base **204**. Duct **206** passes through base **204** and opens into the interior of bell jar **172** and the interior of plasma confining enclosure **170**. Duct **206** is connected to a pumping system (not shown) for the proper evacuation of the enclosures. An ionizable atmosphere is established within enclosure **170** by gas supply **208** which is in com-

munication with gas line **210**. Valve **212** is in gas line **210** to provide control for the amount of gas admitted into the enclosures. Line **210** branches into two gas lines **214** and **216** which open into the interior of enclosure **170**.

As in the previously described embodiment, the ion plasma established in the inner enclosure is produced and sustained by two independent cathode and anode pairs. Cathodic filament **220** is connected to the sceondary winding of transformer **222**. Transformer **222** has its primary winding connected to variable alternating current source **224**. Anode power supply **226** is connected between the secondary winding of transformer **222** and anode **228**. Power source **226** is provided to maintain anode **228** positive with respect to cathodic filament **20**. Cathodic filament **220** is mounted in cathode housing **230** which opens into electron deflector **232**. In like manner, cathodic filament **234** is coupled to a source of variable alternating current **236** through the secondary winding of transformer **238**. Cathodic filament **234** is disposed in housing **239** which opens into electron deflector **241**. Cathode **234**'s cooperating anode **240** is coupled to the cathode by connection through the secondary circuit of transformer **238**. Anode power supply **242** is connected between cathode **234** and anode **240** to maintain the anode positive with respect to the cathode. Target **178** is biased negative with respect to an ion plasma devedoped within enclosure **170** by connection to the negative terminal of target power supply **246**. The positive terminal of target power supply **246** is connected to anode **240** to maintain the proper negative bias on the target.

The plasma confining action of enclosure **170** is provided by maintaining it at a positive potential with respect to the cathodes of the sputtering system. This potenial should approach the potential of the sputtering system's anodes. Thus, enclosure **170** is connected through variable resistor **250** to the positive terminal of anode power supply **242**. Resistor **250** provides a load to reduce the potential on enclosure **170** which in this embodiment is electrically conductive.

Each of the electron deflectors illustrated in FIGURE 4 opens into enclosure **170** through a narrow slit which parallels substrate **174** and bottom plate **176**. This is shown to best effect in FIGURE 5. Electron deflector **232** has a slit **252** which faces anode **240** and the interior of enclosure **170**. The slit enables the electrons entering enclosure **170** to do so in a sheet-like form.

The ion-plasma confining enclosure performs its function by providing the means for maintaining a positive charge which suppresses the normal expansion of the ion plasma into the outer enclosure. This charge can be created by maintaining the component parts of the enclosure in an electrically floating state or by biasing them to a sufficiently positive potential with an independent potential source. Because the confining action is produced by a positive charge on the inner enclosure, the constituent parts of the inner enclosure or the enclosure itself need not be gastight. In addition, use of dielectric materials as the inner enclosure's parts is also possible. Glass, for example, when exposed to the ion plasma will take on a charge and become electrically floating resulting in the repulsion of ions which would otherwise strike the glass or escape into the outer enclosure.

The operation of sputtering apparatus will now be described with reference to FIGURE 1. Enclosures **12** and **14** are pumped down in a normal manner to a low pressure. An ionizable gas such as argon is admitted through valve **136** into ion-plasma confining enclosure **14**. Cathodic filament **22** and its cooperating anode **20**, as well as cathodic filament **18** and its cooperating anode **16**, are energized. Target **24** is biased negative through target power supply **92**. The resulting ion plasma generated within enclosure **14** will be in a sheet-like form having a relative uniform intensity over target **24** and a relatively high concentration of ions. The positive charge on side members **34** and **36** prevents the ion plasma from escaping into outer enclosure **12** while the charge on top and bottom members **31** and **32** performs a confining function and acts on the ion plasma to establish and maintain its sheet-like configuration. By providing two independently energized cathode and anode pairs, operative to draw electrons into the inner enclosure in opposite direction, the intensity of the ion plasma and the sheet-like form is enhanced. The sheet-like form is enhanced because the plasmas emanating from shields **60** and **69** diverge in a horizontal plane but overlap over target **24**.

The invention has been described with reference to certain preferred embodiments. The scope and spirit of the appended claims should not, however, be necessarily limited to the foregoing description.

What is claimed is:

1. In an apparatus for depositing thin films of material on a surface of a substrate which includes a first evacuable enclosure, means for evacuating said enclosure and providing an ionizable atmosphere therein, the improvement comprising:

a second evacuable enclosure located within and electrically insulated from said first enclosure and communicating with said means for establishing an ionizable atmosphere, said second enclosure having at least a first and a second side;

means for establishing an ion plasma within said second enclosure, said means including a first anode and cathode electrically coupled and disposed to cause an electron field in one direction through said second enclosure and a second anode and cathode electrically coupled and disposed to cause an electron field through said second enclosure in a direction opposite that caused by said first anode and cathode;

an ion target having a surface of material to be sputtered with the sputtering surface facing said ion plasma;

means for applying an ion attracting voltage to said ion target; and

means for mounting said substrate within said first enclosure with said surface of the substrate being spaced from and facing the surface of said target so that material sputtered from said target is received by said substrate.

2. A sputtering apparatus as recited in claim **1** wherein the apparatus includes:

means for establishing and maintaining a positive charge on said second enclosure of sufficient magnitude to at least confine the ion plasma therein into a sheet-like form between said target and said substrate.

3. A sputtering apparatus comprising:

(a) an enclosure adapted to confine an ion plasma, the enclosure including first and second spaced-apart members having substantially parallel inner surfaces;

(b) means for evacuating and establishing an ionizable atmosphere within the enclosure;

(c) means for establishing an ion plasma within the enclosure;

(d) means associated with the enclosure for establishing and maintaining a positive charge of sufficient magnitude to at least substantially confine the ion plasma therein and to maintain the plasma in sheet form between the first and second members' inner surfaces;

(e) means for mounting a target of material to be sputtered in ion communication with and parallel to the sheet-like ion plasma;

(f) means for biasing the target to attract ions from the ion plasma; and

(g) means for mounting a substrate in position to receive sputtered material from the target such that the substrate is parallel to and facing the target.

4. The sputtering apparatus claimed in claim **3** wherein the means for maintaining a positive charge includes means for maintaining the ion-plasma confining en-

closure in an electrically floating condition whereby the enclosure is capable of accepting and retaining a positive electric charge from the ion plasma that repulses its ions.

5. The sputtering apparatus claimed in claim 4 wherein the means for establishing an ion plasma includes:

a first cathode and anode electrically coupled together and disposed to cause an electron attracting field in one direction in the ion-plasma confining enclosure; and

a second cathode and anode electrically coupled together independently of the first cathode and anode and disposed to cause an electron attracting field in the ion-plasma confining enclosure opposite that produced by the first cathode and anode;

the substrate and target mounting means being disposed to mount the substrate and target substantially at the center of the ion plasma.

6. The sputtering apparatus claimed in claim 5 wherein the first and second anodes are disposed across the ion-plasma confining enclosure at either end thereof.

7. The sputtering apparatus claimed in claim 5 wherein the means for establishing an ion plasma includes an electron deflector for each cathode, each deflector having a slit-like opening extending transversely across and facing into the ion-plasma confining enclosure.

8. The sputtering apparatus claimed in claim 3 wherein:

(a) the means for establishing an ion plasma includes at least one cathode and at least one anode; and

(b) the means for establishing and maintaining a positive charge includes biasing means operable to maintain the ion-plasma confining enclosure at a potential positive with respect to the cathodes and approaching the anodes' potential.

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