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[54] RF SPUTTERING APPARATUS AND METHOD

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[52] **U.S. Cl.** **204/192,** 204/298
[51] **Int. Cl.** **C23c 15/00**
[58] **Field of Search** 204/192, 298

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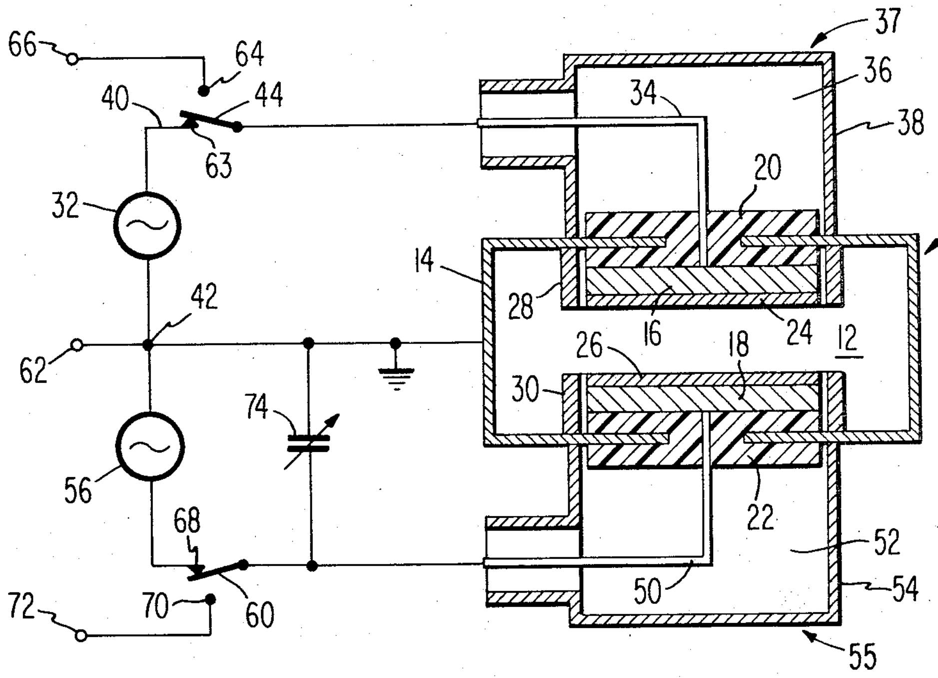
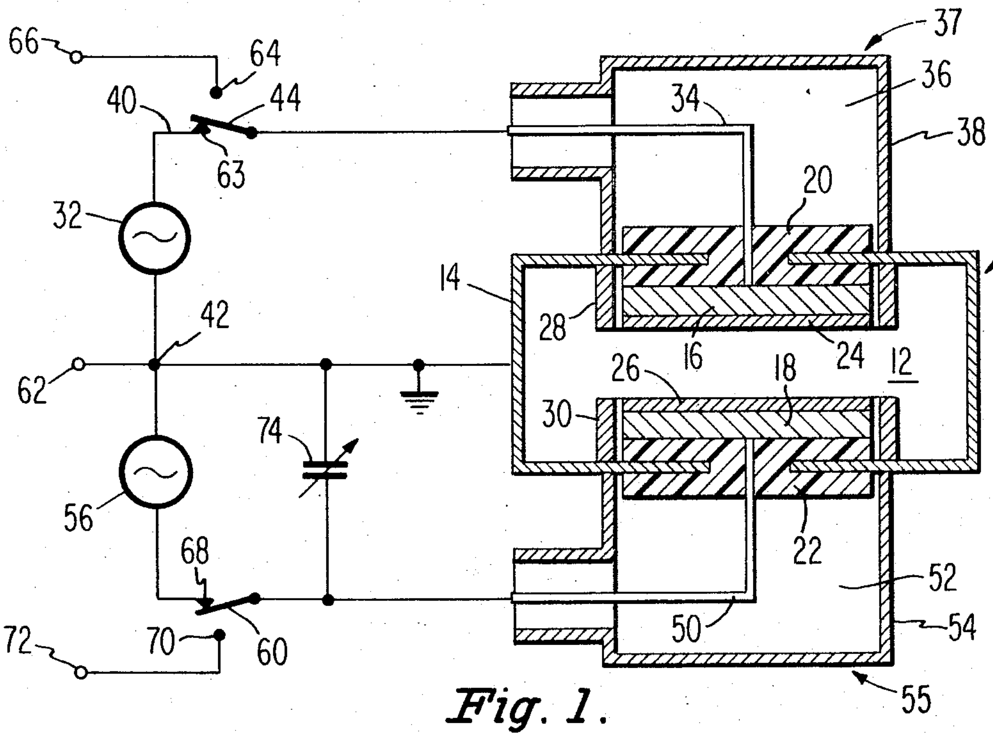
[57] ABSTRACT

An RF bias sputtering apparatus is provided having simple on-off operation in which there is no detuning of the apparatus to an RF power source when sputtering conditions within the ionization chamber change. The capacitive reactances within the chamber and without the chamber are divided into a reactance bridge network, a capacitive reactance means being disposed across an arm of the bridge for balancing the reactances of the bridge network. Critical tuning requirements are reduced by the use of an RF power source with wide bandwidth tuning capabilities.

10 Claims, 4 Drawing Figures




66
64
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74
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Fig. 1.

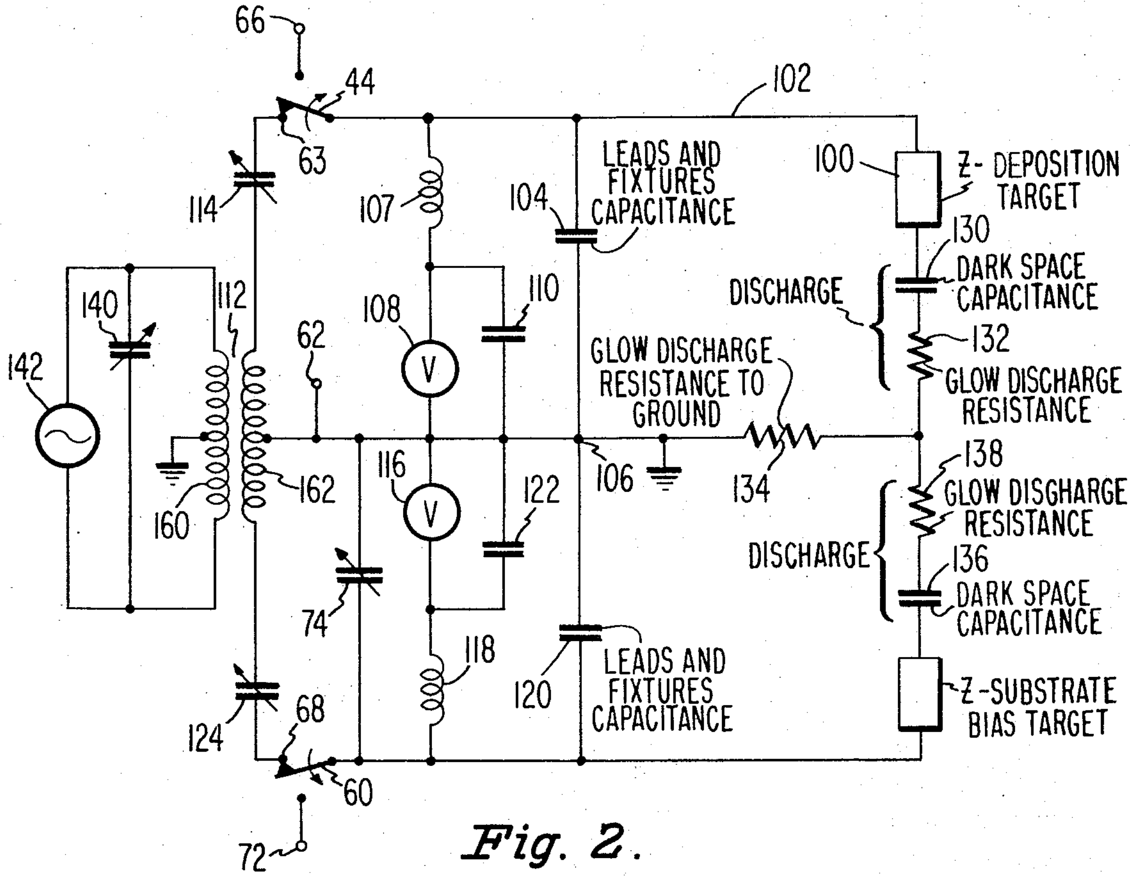
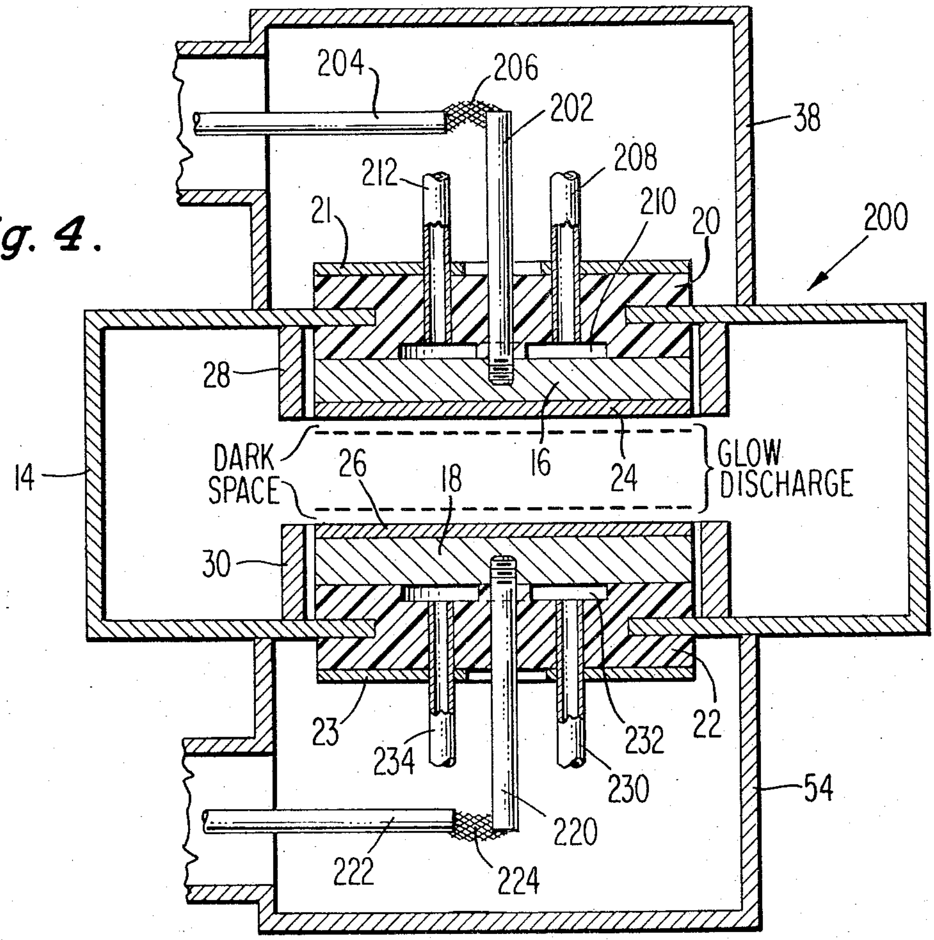

66
44
102
63
114
107
104
LEADS AND FIXTURES CAPACITANCE
100
Z- DEPOSITION TARGET
130
DISCHARGE
DARK SPACE CAPACITANCE
132
GLOW DISCHARGE RESISTANCE
142
140
112
62
108
V
110
GLOW DISCHARGE RESISTANCE TO GROUND
160
162
116
V
106
134
122
138
GLOW DISGHARGE RESISTANCE
DISCHARGE
136
DARK SPACE CAPACITANCE
74
118
120
LEADS AND FIXTURES CAPACITANCE
124
68
60
72
Z -SUBSTRATE BIAS TARGET

Fig. 2.

Fig. 4.


204
206
202
38
212
208
210
21
20
200
28
14
DARK SPACE
26
18
16
24
GLOW DISCHARGE
30
23
234
232
22
230
54
220
222
224

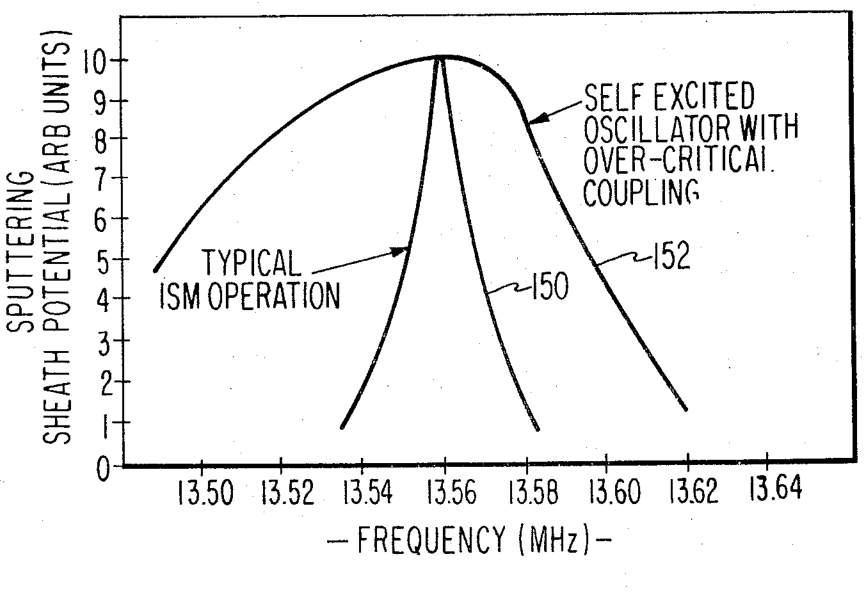

SPUTTERING SHEATH POTENTIAL (ARB UNITS)
10
9
8
7
6
5
4
3
2
1
0
SELF EXCITED OSCILLATOR WITH OVER-CRITICAL COUPLING
TYPICAL ISM OPERATION
150
152
13.50
13.52
13.54
13.56
13.58
13.60
13.62
13.64
— FREQUENCY (MHz) —

Fig. 3.

RF SPUTTERING APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

The sputtering of materials by radio frequency fields is generally known and is discussed in an article by J. L. Vossen appearing in the Journal of Vacuum Science and Technology, Vol. 8, No. 5, Sept./Oct. 1971. Deposition of a thin film by RF bias sputtering is achieved in a vacuum ionization chamber which is typically a metallic housing. The material to be sputtered is placed on a target electrode disposed within the chamber and electrically insulated therefrom. Positioned parallel to and spaced from the target electrode is a second target electrode which supports a workpiece to be coated with a film that is sputtered from the material on the first-mentioned target electrode. An RF power source is arranged to supply an RF potential across both target electrodes to produce a glow discharge in the region between the two targets. The conductive surfaces of the chamber determine the reference potential of the plasma within the chamber. The plasma is defined as a nearly field free region in the space occupied by positive and negative charges.

In addition to plasma, the space between the two target electrodes also includes what is known as a "dark space." The "dark space" is a region adjacent the electrode wherein the voltage drops from the RF potential to a potential close to that of the metallic housing of the chamber. With a single RF potential and a grounded second electrode, there is but one dark space which is adjacent to the first-mentioned electrode. Thereafter the glow discharge region is nearly field free up to the second electrode.

In the known RF sputtering techniques, the RF power may be supplied solely across the first-mentioned electrode with the second electrode having the potential of the conductive housing of the ionization chamber. In this case there is a grounded workpiece target electrode and the material to be sputtered is removed from the first-mentioned electrode to the second electrode by the sputtering technique.

In a negative bias sputtering apparatus the negative bias is applied to the second electrode. Negative bias results in some of the material on the second electrode being sputtered therefrom and removed. The differences in RF potential applied to the two electrodes can be used to improve the properties of certain materials coated on the workpiece on the second electrode, the rate of deposition and other characteristics as known in the RF sputtering art.

It has been found that where the material to be sputtered is a metal, the sputtering technique introduces electrical properties in the deposited film which are different from the electrical properties of a bulk material. That is, there is increased resistivity among other characteristics in the deposited film. It has been found that these differences in characteristics can be reduced. In some cases, the characteristics of the bulk material may be imposed into the deposited thin film by the use of what is known as bias sputtering. However, with present state of the art RF sputtering techniques, such an operation is limited by the limited voltages available or by the complexity of the equipment itself.

Tuning in the range of 13.36 MHz ± 0.00678 MHz has been generally considered required for apparatus in the field of RF sputtering. Power sources are generally frequency sensitive and tend to self-destruct should the apparatus detune as might occur by slight changes of the load impedances within the ionization chamber. Several different controls are usually provided with such apparatus for the tuning of the power source and the various impedances in the matching networks between the load including the connections of the apparatus and the power source. As many as six different tuning and adjusting controls may be present for a single Rf sputtering operation. Additionally, because of the narrow range of frequencies to which the system must be tuned, skilled operators are required to maintain constant monitoring alert over the adjustment of the various controls and even then, uncontrolled sputtering conditions may occur. As a result, such sputtering techniques are not readily adapted to mass production operations.

In accordance with the present invention, high RF powers may be utilized up to several thousand volts on both the target electrode mounting the sputtering material and the target electrode mounting the workpiece. In the present invention, an RF sputtering apparatus is coupled as a bridge network and the impedances in the system are then balanced. An operator need only turn the system on and off after the system is balanced. Regardless of any change in impedances within the ionization chamber the balanced bridge arrangement as originally established within the apparatus remains, permitting an unskilled operator to utilize the apparatus.

SUMMARY OF THE INVENTION

The aforementioned problems are overcome in an RF sputtering apparatus including first and second target holder electrodes disposed within an ionization chamber exhibiting a glow discharge and RF power connecting means for coupling the electrodes to a source of Rf power, the glow discharge exhibiting first ans second impedances between the electrodes, the apparatus within and without the chamber exhibiting third and fourth impedances between the electrodes. A fifth impedance is provided having a value such that when it is coupled across one of the third and fourth impedances a sixth impedance is formed therewith having a value the same as the value of the other of the third and fourth impedances.

The method comprises changing the value of one of the third and fourth impedances to match the other of the third and fourth impedances so that the values thereof are the same.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic circuit diagram and apparatus constructed and operated in accordance with an embodiment of the present invention,

FIG. **2** is a more detailed circuit diagram of the arrangement of FIG. **1**,

FIG. **3** is a graph of curves useful in explaining the present invention, and

FIG. **4** is a cross sectional view of a preferred embodiment of a portion of a sputtering apparatus constructed in accordance with the present invention.

DETAILED DESCRIPTION

In FIG. **1** sputtering apparatus **10** has a low pressure ionization chamber **12** formed by a metallic housing **14**. A suitable gas, as known in the RF sputtering art, is introduced into the chamber **12** inlet (not shown) and maintained at a low pressure by means of a vacuum pump (not shown). Target electrodes **16** and **18** are disposed within chamber **12** by suitable means and electically insulated from housing **14.** As shown, electrical insulation **20** serves as a mechanical support and electrical insulation means for electrode **16,** while insulation **22** serves as a mechanical support and electrical insulation means for electrode **18.**

Mounted on electode **16** is a disk **24** formed of material to be sputtered. Mounted on electrode **18** is a disk **26** of material on which the film of material sputtered from disk **24** is to be deposited. Disk **26** will hereinafter be referred to as the substrate. Surrounding electrode **16** and disk **24** is a metallic cylindrical shield **28** which is ohmically connected to housing **14.** A similar shield **30** encloses the outer periphery of disk **18** and substrate **26** and is ohmically connected to housing **14.** Shields **28** and **30** serve to shield the electrodes and associated disks mounted thereon from exposure to the ionization chamber at the peripheral edges of the electrodes and disks.

Electrode **16** is coupled to an RF power source **32** by way of center conductor **34,** air dielectric **36** and outer shielding conductor **38** which is connected to housing **14.** Center conductor **34,** air dielectric **36** and shield conductor **38** form a first coaxial RF transmission line **37.** This transmission line is coupled to source **32** by way of lead **40** through double pole switch **44** in one switch position thereof by way of switch terminal **63.** The other switch position of switch **44** couples terminal **66** by way of switch terminal **64** to conductor **34.** In this latter switch position a capacitane meter (not shown) can be serially connected between conductor **34** and housing **14** as will be explained. Source **32,** terminal **62** and housing **14** are connected to a point of reference potential, preferably ground.

In a similar manner, electrode **18** is connected to center conductor **50** surrounded by an air dielectric **52** in turn, surrounded by a conductive shield **54,** which together form a second RF coaxial transmission line **55.** Conductor **50** is electrically coupled to housing **14** by way of serially connected double pole switch **60** and RF power source **56.** First terminal **68** of switch **60** is ohmically coupled to RF power source **56** while a second terminal **70** is coupled to terminal **72.**

Switch **60** conductively couples either terminal **68** or **70** with conductor **50** in accordance with the switch position of this switch. As provided in accordance with the present invention, a variable capacitance **74** is coupled between housing **14** and conductor **50.** Capacitance **74** is adjustd so as to balance the capacitive reactive impedances between housing **14** and conductor **50** formed by transmission line **55** and associated fixturing to the capacitive reactive impedances between housing **14** and conductor **34** formed by transmission line **37** and associated fixturing. The capacitive reactance between either of conductors **34** and **50** and housing **14** comprises the capacitance between electrodes **16** and **18** to the housing **14** and the capacitance between leads **34** and **50** and outer shielding conductors **38** and **54,** repectively. One source of difference in capacitance between transmission lines **37** and **55** is, of course, a difference in length thereof.

Adjustment of variable capacitor **74** is achieved by placing a capacitance measuring meter (not shown) between terminals **62** and **66** and measuring capacitive reactances present between conductor **34** and housing **14** making note of same. The capacitor meter is then placed between terminals **62** and **72** to measure the capacitive reactance present between housing **14** and conductor **50.** Of course, the switch positions of switches **44** and **60** are positioned such as to place terminals **66** and **72** respectively in ohmic contact with the respective center conductors **34** and **50** of transmission lines **37** and **55.** Capacitor **74** is then adjusted such that the capacitive reactance between housing **14** and conductor **50,** comprising the reactance of capacitor **74** in addition to the capactive impedance provided by the RF coaxial transmission line including conductor **50,** air dielectric **52** and outer conductor **54,** and the fixturing within the chamber **12** is the same as the capacitive reactance previously noted between conductor **34** and housing **14.** Note that switches **44** and **60** each disconnect the respective power sources **32** and **56** during the measurement of the capacitive reactances.

In FIG. 2 there is illustrated a circuit schematic diagram representing the electrical equivalents of the apparatus of FIG. **1** in addition to additional components provided in accordance with a particular practical application of the apparatus constructed in accordance with the present invention. In FIG. 2 like numerals refer to like components of FIG. **1.** In FIG. 2, the impedance **100** of the deposition target such as provided by disk **24** of FIG. **1** and its connection to electrode **16** is considered to be negligible. This may be in the order of a few ohms. Impedance **100** is coupled by way of lead **102** to switch **44.** In effect lead **102** represents the ohmic coupling of electrode **16** to switch **44** of FIG. **1.** Capacitor **104** represents the capacitive reactances between lead **102** and the reference potential at terminal **106** manifested by housing **14** of FIG. **1.**

Coupled across capacitor **104** is RF choke **107** which is serially connected to a D.C. volt meter **108.** Across D.C. volt meter **108** is an RF bypass capacitor **110.** Terminal **62** is connected to the center tap of RF transformer **112** whose one power output side is serially connected to terminal **63** through variable voltage setting capacitor **114.**

In a like manner a volt meter **116** is serially connected to RF choke **118** across capacitance **120** which manifests the capacitance of the RF connections between electrode **18** and switch **60** of FIG. **1** to reference terminal **106.** Across D.C. volt meter **116** is coupled RF bypass capacitor **122.** RF choke **107** and capacitor **110** serve respectively to reduce and bypass the RF power to D.C. volt meter **108,** permitting meter **108** to measure D.C. voltages without being destroyed by the RF power applied from transformer **112.** In a like manner RF choke **118** and capacitor **112** reduce and bypass RF power D.C. meter **116** to protect meter **116** from destruction by the RF power. Variable capacitance **74** is coupled between terminal **62** and switch **60** across capacitance **120.** Terminal **68** of switch **60** is serially coupled through variable voltage setting capacitor **124** and the RF power source manifested by transformer **112** to terminal **62** by way of the center tap of transformer **112.** Capacitors **114** and **124** each independently set the power level applied across terminals **63** and **62** and across terminals **68** and **62,** respectively.

In many sputtering operations, the active agent is a glow discharge maintained between spaced electrodes in a suitable gaseous medium. Under the influence of the electric field established between electrodes, ionization of the gas is produced by the collision of free electrons with the gas molecules, producing positively charged gas ions. These ions are attracted toward the electrodes thereby creating what is known as an "ion sheath" around the electrode. This "ion sheath" is the same as the "dark space" referred to earlier. Within this region the ions are subjected to a high potential which accelerates them toward the electrodes so that they bomard the target disposed on the electrodes with sufficient impact to eject particles therefrom. These ejected or "sputtered" particles of target material will be deposited on nearby objects. In the particular apparatus described herein the sputtering material is deposited upon articles that are mounted on the substrate electrode.

That portion of the glow discharge present outside the ion sheath (dark space) surrounding the electrodes is a nearly field free area. That is, nearly all the entire potential drop between the electrode and ground or reference potential occurs across the dark space. The dark space noted will appear adjacent to that electrode at which there is applied a negative RF potential. If one of the electrodes in a system such as illustrated in FIG. 1 does not have an RF power source applied thereto, but is at ground potential, then the dark space will appear at the one electrode at which the RF power is applied. If on the other hand, a negative RF potential is applied to the other electrode in the system, then the dark space will appear adjacent to both electrodes.

This latter arrangement is known as RF bias sputtering. RF potential applied to the second electrode will cause some removal of the material (substrate) or sputtering thereof due to the RF potential applied to this electrode. In effect with a high voltage applied to one electrode and a low voltage to the other, the low voltage electrode and its corresponding substrate mounted thereto will receive a thin film of a sputtered material some of which is resputtered therefrom.

This resputtering action or RF bias sputtering has been found with respect to certain materials to cause the deposited materials on the substrate to exhibit bulk properties of the sputtered material from the high powered electrode whereby without bias sputtering the thin deposited film will have properties which are not the same as the bulk material being sputtered from the high powered electrode.

It has been found that with certain sputtering material such as refractory materials including tantalum and molybdenum, the deposited thin films without bias sputtering do not exhibit the same electrical resistivity properties as the bulk material. However, to provide the deposited thin film with nearly the same electrical properties as the bulk materials it has been found that a negative bias voltage is required in the neighborhood of 150–200 volts. Prior art systems have proved to be extremely complex and sensitive in providing such bias sputtering voltages.

As indicated above, in an RF bias sputtering apparatus, there is present a dark space adjacent a deposition target and the substrate bias target. This dark space is represented electrically as a capacitance. Between the two dark spaces is the glow discharge region. This glow discharge region is represented electrically as a resistance. In prior art systems there is generally provided impedance matching networks between both the deposition target and the power source and the substrate bias target and the power source in addition to tuning controls in the RF power source itself which is critically tuned to the frequency of the matching impedance networks. Any slight shift in the values of the disributive capacitance impedances within the apparatus will cause a detuning to result and possible burnout of the output tubes of the power amplifier which ordinarily are tetrodes or pentodes. As sputtering conditions change which very often will occur rapidly, the power source and load may not always be in perfect matching tuning. As a result a skilled operator has to manipulate a minimum of four tuning controls and a power control to return the source to the load.

It has been found that the dark space capacitance **130** associated with electrode **16** and a portion of the resistance **132** formed by the glow discharge in the chamber is coupled to the ground terminal **106** manifested by housing **14** through a small resistive impedance **134** of a few ohms which is the glow discharge resistance to ground. The second dark capacitance **136** is formed by the dark space associated with the substrate bias target **18**, and a resistive impedance **138** is formed by the glow discharge resistance between the capacitance **136** and ground terminal **106** again through resistive impedance **134.**

Capacitance **120** in combination with dark space capacitance **136** and glow discharge resistance **138** form one-half of a reactance bridge network. The capacitance **104** and dark space capacitance **130** and glow discharge resistance **132** associated with the deposition target electrode form the other half of that bridge network. By providing an impedance bridge matching capacitor **74** in accordance with the present invention, the capacitive reactance associated with the substrate bias target may be matched to the capacitive reactance assoicated with the deposition target. By so doing, any shift of capacitive reactances within the ionization chamber due to changing sputtering conditions will have no substantial effect on the balanced reactance of the bridge, since the glow discharge coupling to ground will itslef be uniformly divided with respect to the deposition targets and substrate bias targets and ground. As long as this division is present within the ionization chamber, then the effects of changing sputtering conditions will not cause an appreciable change in load conditions with respect to the RF power source. With this in mind, the power source after the bridge network is balanced, need only be turned on and off once the source is tuned to the load by way of tuning capacitor **140** disposed across transformer **112** and the power to each of the deposition and substrate bias targets is set by variable capacitances **114** and **124,** respectively. The meters **108** and **116** permit setting of these respective voltages. The RF power source at transformer **112** is indicated as source **142** in FIG. **2.** As a result, no matching impedances need be inserted in the circuit nor set by a skilled operator to match the load to the power source In this case, the matching impedance is provided by matching the characteristic impedance of the coaxial transmission lines **37** and **55** (FIG. **1**) to the RF power source (transformer **112**).

Since the RF connections icluding the coaxial transmission lines and fixtures are rigid and, therefore, fixed in a given apparatus, then once capacitor **74** is adjusted such that the combination thereof with capacitance **120** balances the capacitance of capacitance **104,** there is no need for further variation of capacitor **74** in the operation of the apparatus of the present invention. In a similar manner, tuning capacitor **140** need be set once during an operation at the start thereof for matching the source to the load in a conventional manner. It is to be understood that switches **44** and **60** coupled to terminals **66** and **72** disconnect capacitors **114** and **124** and transformer **112** from the remainder of the circuit thereby enabling conventional capacitance meters, when placed across respective terminals **66** and **72** and terminal **62** to measure only the capacitance provided by the apparatus.

FIG. **3** illustrates the plot of sputtering sheath potential in arbitrary units (ARB) versus frequency in MHz. Curve **150** is a plot of the Industrial, Scientific and Medical (ISM) frequency allocated by the Federal Communications Commission of the United States Government which has found widespread use with RF sputtering equipment. This ISM frequency is 13.56 MHz ± 0.00678 MHz. In the use of such a narrow frequency band, a typical RF sputtering apparatus is easily detuned and crystal controlled oscillators are necessarily employed therewith for maintaining such a narrow range of frequencies. The ISM frequencies have been designated in order to prevent unlicensed operation and unlimited radiation in ranges outside this frequency to avoid interference with other equipment such as communication equipment and the like allocated to adjacent frequencies in the crowded RF spectrum. In effect, the Federal Communications Commission has indicated that spurious and harmonic radiation frequencies other than those specified shall be suppressed so that such radiations do not exceed a field strength of **25** microvolts per meter at a distance of 1,000 feet or more from the equipment causing such radiations. In sputtering equipment ordinarily using 13.56 MHz, the eighth harmonic falls in an aircraft navigation band which uses receivers with a sensitivity of 2 microvolts per meter. It has been found that by employing apparatus of the present invention levels of RF power radiated by the equipment are less than those amounts prohibited by the Federal Communications Commission. As a result, frequencies outside the ISM range may be utilized in this equipment without generating spurious harmonic radiations in the prohibited frequency ranges. In view of this, a crystal controlled oscillator need not be used as a signal source **142** but rather a self-excited oscillator with over-critical coupling may be provided having the characteristics of curve **152** of FIG. **3.** In effect, as provided by the present invention, tuning of the source may be set somewhere around the 13.54 MHz range or at any other convenient frequency, permitting deviations of the tuning without substantially affecting the sputtering sheath potential. Note on curve **150** the large drop off of sheath potential when the ISM frequency of 13.56 is slightly deviated from the center frequency as might occur with changing sputtering conditions in a sputtering apparatus. In accordance with the present invention, an operator need only turn on the source of RF power once the various variable capacitances **140, 114, 124** and **74** have been initially adjusted. Thus this apparatus is readily adapted for production techniques utilizing unskilled labor. This provides a marked improvement over prior art systems in that highly skilled labor is required for those systems for the reasons discussed above.

Transformer **112** of FIG. **2** includes a primary inductance **160** and a secondary inductance **162** and the slightly overcritical coupling may be achieved by choosing appropriate values of the inductances **160** and **162** and the value of tuning capacitance **140** across transformer **112.** Inductance **162** is concentric with inductance **160** in a particular practical embodiment thereof and is water cooled to prevent RF heating. This results in a loosely coupled transformer that is primarily tuned by varying capacitance **140,** when the sputtering chamber geometry is fixed. Capacitance **140** can be tuned once and locked into position. In one embodiment, a three kilowatt push-pull power supply, **142,** applies D.C. sheath potentials that can be impressed across 8 inch diameter targets. The target voltage range from −15 to −3,000 volts. This is accomplished with the primary tuning of the source at a frequency to a little to the left of the broad maximum tuning peak of waveform **150** of FIG. **3.**

With this system, depending upon the arrangement of the internal fixturing, a wide range of operating frequencies is possible. For example, the operating frequency can be in the range of 3 to 8 MHz.

If bias voltages lower than −15 volts are required, the system is first tuned to minimize voltage on the target in question, and then the target is directly shorted to ground through a switch (not shown). When high voltages are required on a lower target in a particular operating system, and, simultaneously, very low voltages are required on the upper target, it is desirable to reduce the capacitance of capacitor **74** to its minimum to conserve power. Ordinarily the value of capacitor **74** is fixed to balance the bridge circuit and left at that value permanently.

In a typical sputtering process the sequence involved includes simultaneously pre-sputtering the upper target to clean it and sputter-etching the substrates either to clean them or to back scatter material onto them. The voltage on the substrate target is then reduced to the desired bias voltage level. A shutter (shield disposed between the two electrodes in the ionization chamber) is removed and deposition is commenced. In many different mechanical target configurations in a practical embodiment constructed and operated in accordance with the present invention, it has been found possible to change the sputtering voltages from one condition to another by simply changing the value of the series capacitor **124.** To de-skill the operation for production purposes, it is possible to use two capacitors (not shown) and a switch (not shown) to replace capacitor **114** of FIG. **2.** One of the capacitors would be set to the target clean and sputter-etch condition, while the other is set for the bias deposition, and the change from one condition to the other would be by way of an RF switch (not shown). Thus the operator would only have an on-off control, a switch and a power control to manipulate. The system has been found to be extremely stable. This can be shown as illustrated by the following examples:

EXAMPLE 1

A system constructed and operated in accordance with the present invention has been run for continuous periods of up to eight hours each with different targets and target geometries. (See table I).

TABLE I

Target Materials, Geometry, Voltages

Test No.	Upper Target	Lower Target	V Upper Target	V Lower Target	Time of Test
1	8" dia., 304 Stainless Steel (Bonded)	Same as Upper Target	−2000 V	− 200 V	8 hrs.
2	Same as Test No. 1	Same as Test No. 1	−2000 V	−2000 V	2 hrs.
3	8" dia, NiO (Flame Sprayed)	8" dia., 304 Stainless Steel (Bonded)	− 500 V	− 500 V	1 hr.
4	Same as Test No. 3	Same as Test No. 3	−1000 V	− 20 V	1 hr.
5	Same as Test No. 3	Same as Test No. 3	−1000 V	− 75 V	3 hrs.
6	Same as Test No. 3	Same as Test No. 3	−1000 V	− 150 V	3 hrs.
7	6" dia., Mo (Clamped)	5¾" dia., Mo (Unclamped)	−1000 V	− 150 V	5 hrs.
8	Co-sputtering ½ Ni Target ½ SiO_2 Target (Clamped)	8" dia., 304 Stainless Steel (Bonded)	−1000 V	− 50 V	3 hrs.
9	Same as Test No. 8	Same as Test No. 8	−1000 V	− 150 V	3 hrs.
10	Same as Test No. 8	Same as Test No. 8	−1000 V	− 150 V	3 hrs.

In no case did the target voltages vary from those initially set up to the limits of readibility of the voltmeters (2%). These voltages were also stable when there were wide variations in gas pressure. (See Table II).

TABLE II

Gas Pressure Fluctuation Effects on Target Voltages; Targets, Geometry, and Tuning Fixed

	Argon Pressure (Varied)	Volts Upper (Fixed)	Volts Lower (Fixed)
Initial Condition:	30 millitorr	−1000 V	− 200 V
	40 millitorr	−1000 V	− 200 V
	50 millitorr	−1000 V	− 200 V
	60 millitorr	−1000 V	− 200 V
	70 millitorr	− 980 V	− 190 V
	80 millitorr	− 950 V	− 185 V
	90 millitorr	− 930 V	− 180 V

For example, the variations might occur during very severe outgassing from very porous targets, and during the initial sputtering of oxidized metal targets when the secondary electron emission coefficient changes very rapidly as the oxide is sputtered away. When either the pressure or the secondary electron yield varies, the impedance of the discharge is changed. It is well known that the secondary election emission yield of compounds (and particularly, oxides) is greater than that of the constituent elements of the compound. Thus, in a sputtering process, if a metal target surface is oxidized, the initial sputtering will be under conditions of high secondary electron yield. Then, as the oxide is sputtered away, the secondary electron yield decreases. For most oxides, this change can be as large as a factor of 10:1 depending on the exact condition of the target surface.

Additional secondary electrons ejected into the glow discharge produce more current, and so reduce the impedance of the discharge. In contradistinction in crystal controlled systems, even small changes in either pressure or secondary electron yield result in gross system de-tuning.

EXAMPLE II

To provide a worst-case test reproducibility of the system, the following experiment was performed: The upper target was tungsten six inches in diameter, clamped. The other target was also tungsten but was three inches in diameter and was clamped. This yielded an asymmetric geometry. In particular a set of voltage conditions were established as follows on the two targets and the system was run for two hours to assure that there was no possibility that any oxide remained on either target.

Argon Pressure: 50 millitorrs
Upper Target Voltage: −1,000 V
Lower Target Voltage: −200 V

The power and tuning controls were locked in place. Then the RF generator was shut off and O_2 was immediately bled into the system through a pressure of 1 torr and left that way over night. Under these conditions a relatively thick WO_3 layer grows rapidly on tungsten (W) surface. Seventeen hours later, the vacuum chamber was pumped out and the argon sputtering gas pressure used at the start of the test in the ionization chamber was re-established and the generator was switched on. Exactly the same sputtering conditions as existed at the beginning of the test were instantly established without retuning.

For this test, capacitance **114**, capacitance **124** and capacitor **74** were variable capacitances in the range of

7 to 1,000 picofarads at 5 kilovolts. The tuning capacitor **140** for the RF source was a variable capacitor in the range of 10 to 450 picofarads at ten kilovolts rating. Transformer coil **160** was an inductance comprising seven turns of ⅜ inch diameter tubing, six inches in diameter and twelve inches in length. The inductance **162** of transformer coil **112** was twenty turns of ¼ inch diameter tubing, 3 inches in internal diameter, 18 inches in length and was water cooled.

In FIG. 4 there is illustrated a more detailed structure of the ionization chamber, electrodes, and connecting RF coaxial structure described in connection with FIG. **1.** In FIG. **4,** like numerals refer to like elements in FIG. **1.** In FIG. **4,** apparatus **200** includes housing **14,** electrodes **16** and **18,** insulating mounting supports **20** and **22** and shields **28** and **30** as described previously in connection with FIG. **1.** Additionally, metal plates **21** and **23** clamp insulation **20** and **22** and the respective electrodes **16** and **18** to housing **14** as by bolts or other suitable means, not shown. In addition, electrode **16** is shown connected to an electrode terminal **202** which is connected to RF coaxial pipe structure center conductor **204** by way of a braided copper conductor **206.** Coolant inlet pipe **208** is connected to a circular cavity **210** adjacent electrode **16** and exhausted by way of exhaust pipe **212.** Substrate bias electrode **18** is connected to electrode **220** which in turn is connected to conductor **222** by way of braided conductor **224** within the hollow pipe structure of outer conductive shield **54.** Inlet water pipe **230** is connected to the circular channel **232** for cooling electrode **18.** Coolant exhaust pipe **234** is also coupled to channel **232** for exhausting the coolant therefrom.

What is claimed is:

1. In combination:

a plurality of RF power input terminals,

an electrically conductive housing arranged to form an ionization chamber when coupled to a source of reference potential,

a first target holder electrode mounted in said chamber electrically insulated from said housing,

a second target holder electrode mounted in said chamber spaced from said first target holder electrode and electrically insulated from said housing,

first and second RF power connecting means each coupled between a separate, different one of said electrodes and a corresponding, separate, different one of said RF power input terminals, said first connecting means and said chamber exhibiting first and third impedances between the corresponding one electrode and said housing, said second connecting means and said chamber exhibiting second and fourth impedances different from said first and third impedances between the corresponding other electrode and said housing, and

impedance balancing means coupled across one of said first and second impedances for balancing the impedances between said electrodes and said housing.

2. In combination:

a source of RF power including a self-excited oscillator,

first, second and third electrical terminals,

means for connecting said first and second terminals to said source of RF power and said third terminal to a source of reference potential,

an ionization chamber formed by an electrically conductive housing,

a first electrode target holder disposed in said chamber and electrically insulated from said housing,

a second electrode target holder disposed in said chamber spaced from said first electrode target holder and electrically insulated from said housing,

first connecting means electrically connecting said first electrode to said first terminal,

second connecting means electrically connecting said second electrode to said second terminal,

means for coupling said RF power source, said housing and said first and second connecting means to said third terminal, the coupling of said first connecting means to said third terminal exhibiting a first impedance, the coupling of said second connecting means to said third terminal exhibiting a second impedance different from said first impedance producing an impedance unbalance therebetween, and

impedance balancing means coupled between one of said first or second terminals and said third terminal for balancing the coupling impedances between said first and second connecting means and said third terminal.

3. In a method for sputtering a material by RF stimulated glow discharge in an apparatus in which power from a RF power source is impressed through coupling means across a first target electrode associated with a source of material and power from said RF power source is impressed through said coupling means across a second target electrode associated with a substrate workpiece holder for depositing said material on a workpiece, said electrodes being electrically insulated from a conductive surface in contact with the plasma generated in the environment of said electrodes, the steps comprising:

forming first and second impedances between said first and second target electrodes and said conductive surface within said environment,

forming said coupling means including said first and second target electrodes and said conductive surface into third and fourth impedances,

coupling said first, second, third and fourth impedances in a bridge configuration, and

balancing said impedances.

4. The method of claim **3** wherein said third and fourth impedances are capacitive reactances.

5. The method of claim **3** further including the steps of impressing said RF power at the same level across said first and second target electrodes, and then reducing the level across said second target electrode.

6. The method of claim **3** further including the steps of placing a first variable impedance between said RF power source and said first target electrode and placing a second variable impedance between said RF power source and said second target electrode.

7. The method of claim **6** wherein said third and fourth impedances and said variable impedances are capacitive reactances.

8. In an RF sputtering apparatus for establishing a discharge between a bias target electrode and an ionization chamber in which said bias target electrode is located and establishng a discharge between a deposition target electrode and said ionization chamber in which said deposition target electrode is located, by coupling a first source of RF power between said bias target electrode and said ionization chamber and coupling a second source of RF power between said deposition target electrode and said chamber through coupling means, the improvement wherein:

said coupling means is arranged to provide balanced impedances between (i) said bias target electrode and said ionization chamber and (ii) said deposition target electrode and said ionization chamber.

9. In the apparatus of claim **8** wherein there are two discharge portions each corresponding to a separate, different electrode and a third discharge portion common to said two discharge portions when said chamber is grounded, said coupling means grounding said chamber whereby the junction of said two discharge portions and said third discharge portion is at ground potential.

10. In the apparatus of claim **8** wherein said coupling means includes a first power connecting means for connecting said first source of RF power to said bias target electrode, a second power connecting means for connecting said second source of RF power to said deposition target electrode, and means for grounding said chamber, said first power connecting means exhibiting a first impedance, said second power connecting means exhibiting a second impedance different than said first impedance thereby producing an impedance unbalance,

said first mentioned coupling means including a third impedance which together with said first and second impedances balances said impedance unbalance.

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