RF SPATTERING APPARATUS AND METHOD

Inventor: John Louis Vossen, Jr., Somerville, N.J.

Assignee: RCA Corporation, New York, N.Y.

Filed: Nov. 29, 1972

Appl. No.: 310,446

U.S. Cl. ........................................ 204/192, 204/298
Int. Cl. ........................................ C23c 15/00
Field of Search ................................ 204/192, 298

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Primary Examiner—T. M. Tufariello
Attorney, Agent, or Firm—Edward J. Norton; William Squire

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.
SELF EXCITED OSCILLATOR WITH OVER-CRITICAL COUPLING

Fig. 3.

SHEATH POTENTIAL (arb units)

FREQUENCY (MHz)

Fig. 4.
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 determined 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.

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 and 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.
3,860,507

pump (not shown). Target electrodes 16 and 18 are disposed within chamber 12 by suitable means and electrically 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 electrode 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 capacitive 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 capacitor 74 is coupled between housing 14 and conductor 50. Capacitance 74 is adjusted 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 of elements 16 and 18 to the housing 14 and the capacitance between leads 34 and 50 and outer shielding conductors 38 and 54, respectively. 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 capacitive 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 capacitive 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 bypass capacitor 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 bombard 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 network. Any slight shift in the values of the distributive 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 associated 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 itself 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 including 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 match-
ing 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 fixture, 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 1).
### TABLE I

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Upper Target</th>
<th>Lower Target</th>
<th>V Upper Target</th>
<th>V Lower Target</th>
<th>Time of Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8&quot; dia., 304 Stainless Steel (Bonded)</td>
<td>Same as Upper Target</td>
<td>-2000 V</td>
<td>-200 V</td>
<td>8 hrs.</td>
</tr>
<tr>
<td>2</td>
<td>Same as Test No. 1</td>
<td>Same as Test No. 1</td>
<td>-2000 V</td>
<td>-200 V</td>
<td>2 hrs.</td>
</tr>
<tr>
<td>3</td>
<td>8&quot; dia., NiO (Flame Sprayed)</td>
<td>8&quot; dia., 304 Stainless Steel (Bonded)</td>
<td>-500 V</td>
<td>-500 V</td>
<td>1 hr.</td>
</tr>
<tr>
<td>4</td>
<td>Same as Test No. 3</td>
<td>Same as Test No. 3</td>
<td>-1000 V</td>
<td>-20 V</td>
<td>1 hr.</td>
</tr>
<tr>
<td>5</td>
<td>Same as Test No. 3</td>
<td>Same as Test No. 3</td>
<td>-1000 V</td>
<td>-75 V</td>
<td>3 hrs.</td>
</tr>
<tr>
<td>6</td>
<td>Same as Test No. 3</td>
<td>Same as Test No. 3</td>
<td>-1000 V</td>
<td>-150 V</td>
<td>3 hrs.</td>
</tr>
<tr>
<td>7</td>
<td>6&quot; dia., Mo (Clamped)</td>
<td>5% dia., Mo (Unclamped)</td>
<td>-1000 V</td>
<td>-150 V</td>
<td>5 hrs.</td>
</tr>
<tr>
<td>8</td>
<td>Co-sputtering % Ni Target % SiO₂ Target (Clamped)</td>
<td>8&quot; dia., 304 Stainless Steel (Bonded)</td>
<td>-1000 V</td>
<td>-50 V</td>
<td>3 hrs.</td>
</tr>
<tr>
<td>9</td>
<td>Same as Test No. 8</td>
<td>Same as Test No. 8</td>
<td>-1000 V</td>
<td>-150 V</td>
<td>3 hrs.</td>
</tr>
<tr>
<td>10</td>
<td>Same as Test No. 8</td>
<td>Same as Test No. 8</td>
<td>-1000 V</td>
<td>-150 V</td>
<td>3 hrs.</td>
</tr>
</tbody>
</table>

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

### TABLE II

<table>
<thead>
<tr>
<th>Initial Condition</th>
<th>Argon Pressure (Varied)</th>
<th>Volts Upper (Fixed)</th>
<th>Volts Lower (Fixed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 millitorr</td>
<td>-1000 V</td>
<td>-200 V</td>
<td></td>
</tr>
<tr>
<td>40 millitorr</td>
<td>-1000 V</td>
<td>-200 V</td>
<td></td>
</tr>
<tr>
<td>50 millitorr</td>
<td>-1000 V</td>
<td>-200 V</td>
<td></td>
</tr>
<tr>
<td>60 millitorr</td>
<td>-1000 V</td>
<td>-200 V</td>
<td></td>
</tr>
<tr>
<td>70 millitorr</td>
<td>-900 V</td>
<td>-190 V</td>
<td></td>
</tr>
<tr>
<td>80 millitorr</td>
<td>-950 V</td>
<td>-185 V</td>
<td></td>
</tr>
<tr>
<td>90 millitorr</td>
<td>-930 V</td>
<td>-180 V</td>
<td></td>
</tr>
</tbody>
</table>

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 O₂ was immediately bled into the system through a pressure of 1 torr and left that way over night. Under these conditions a relatively thick WO₃ 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 3/8 inch diameter tubing, six inches in diameter and twelve inches in length. The inductance 162 of transformer coil 112 was twenty turns of 3/8 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 establishing 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.