United States Patent

[11] **3,617,459**

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[54] **RF SPUTTERING METHOD AND APPARATUS FOR PRODUCING INSULATING FILMS OF VARIED PHYSICAL PROPERTIES**
12 Claims, 5 Drawing Figs.

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

[56] **References Cited**

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Assistant Examiner—Sidney S. Kanter
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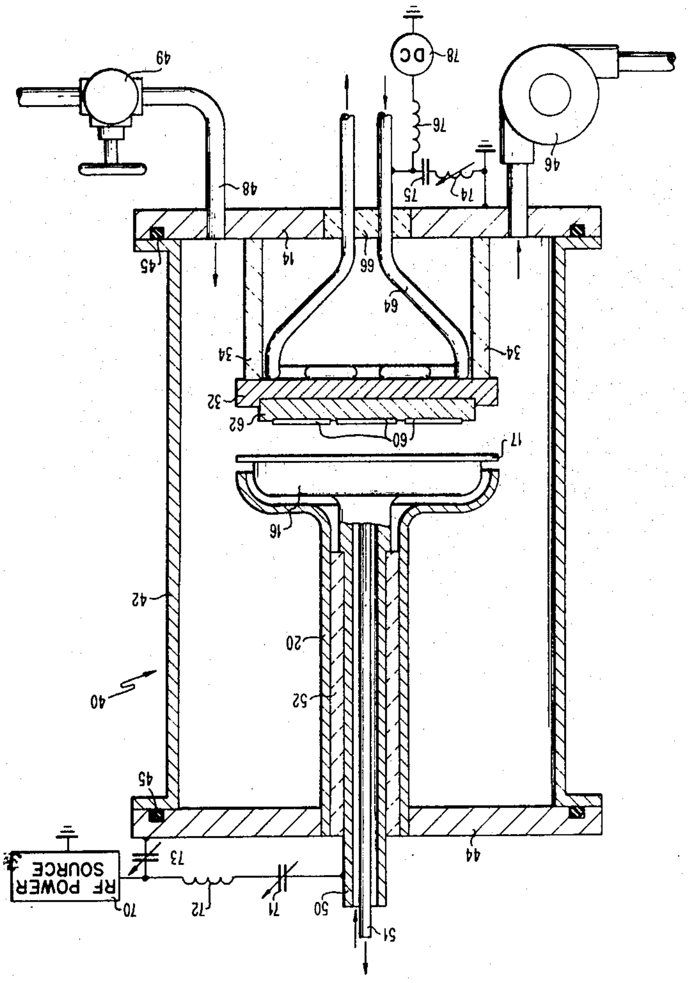
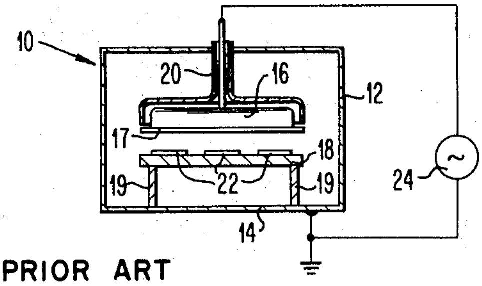
ABSTRACT: An RF sputtering method wherein the potential of the workpiece relative to the plasma is the sputtering chamber is adjusted to provide a control over the physical characteristics of the resulting sputtered films. The apparatus has an insulated target electrode, an insulated workpiece holder electrode, and a conductive surface in contact with the plasma generated by impressing an RF voltage across the target electrode and workpiece holder electrode. An impedance is provided between the workpiece holder electrode and the conductive surface. The impedance provides a control of the workpiece holder voltage.





PRIOR ART

FIG. 1

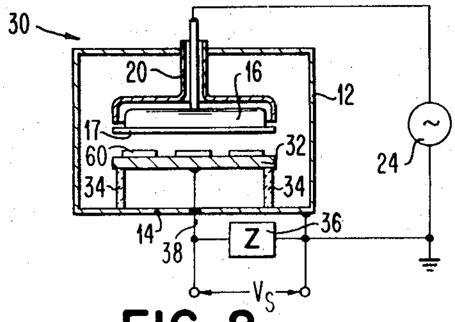


FIG. 2

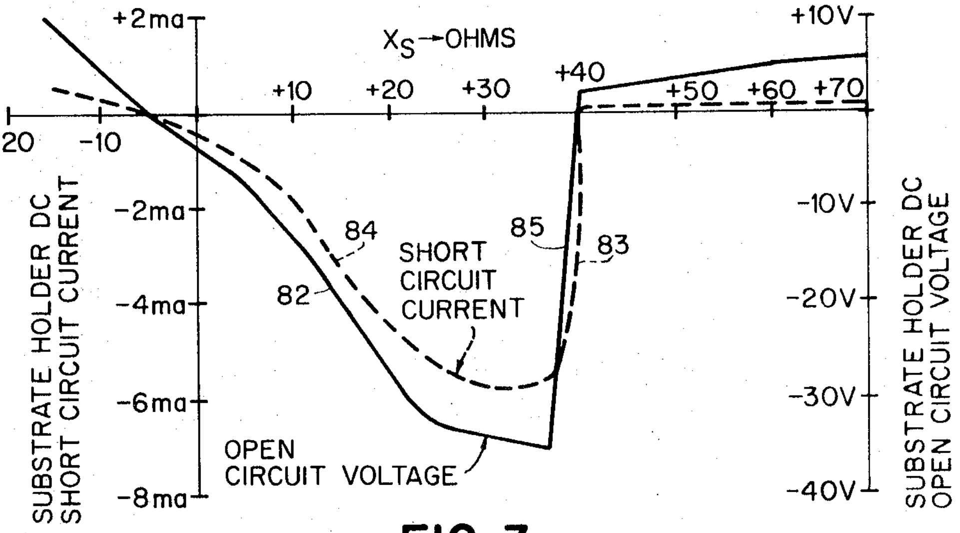


FIG. 3

FIG. 4

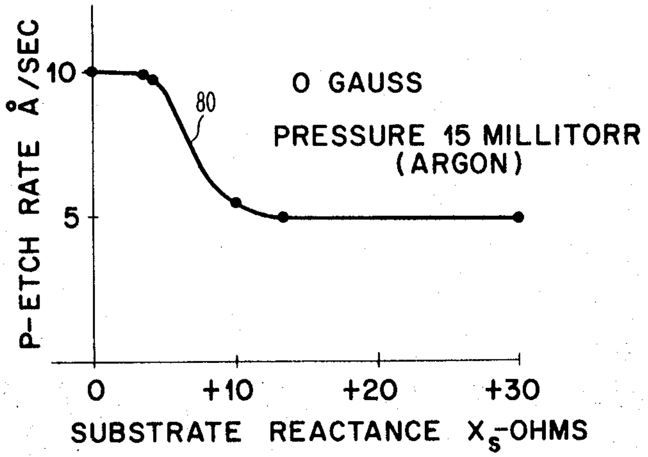


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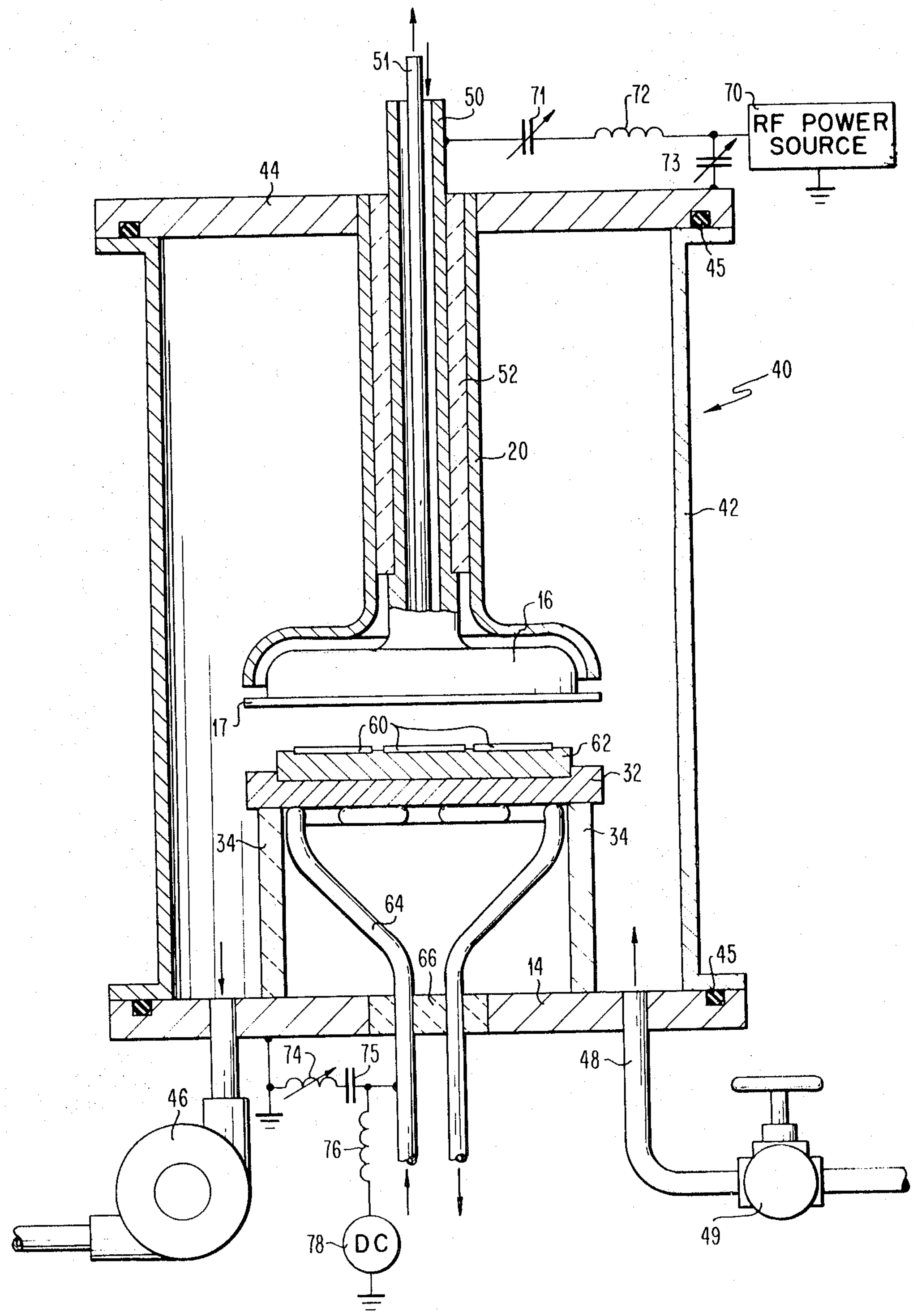
FIG. 5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RF POWER SOURCE
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RF SPUTTERING METHOD AND APPARATUS FOR PRODUCING INSULATING FILMS OF VARIED PHYSICAL PROPERTIES

BACKGROUND OF THE INVENTION

The sputtering of dielectric materials by radiofrequency fields is generally disclosed in an article by G. S. Anderson, William N. Mayer, and G. W. Wehner appearing in the Journal of Applied Physics, Vol 33, No. 10, Oct. 1962. Improvements in the Method and Apparatus for RF Sputtering are disclosed in commonly assigned applications, Ser. No. 428,733, Filed Jan. 28, 1965, now U.S. Pat. No. 3,369,991 and Ser. No. 517,853, Filed Dec. 20, 1965.

Increased interest in the deposition of insulating films by sputter methods has resulted with the development of integrated monolithic and thin film circuit devices. Insulating films of electrically stable high melting or softening point materials can be applied to suitable semiconductor substrates without subjecting the devices to the high temperatures normally required when the same materials are applied by other methods, which high temperatures might otherwise seriously degrade or ruin the device. This greatly increases the choice and range of materials available for insulating, packaging, etc. It makes possible the use of materials and combinations of materials having desirable insulting or conducting properties or other desirable properties which materials could not otherwise be used because of processing requirements, differences in coefficients of expansion of the films, and the materials underlying and overlying same, etc.

The deposition of an insulating film by reactive and direct RF sputtering is normally carried out in a vacuum chamber, which is typically metal. The material to be sputtered is mounted on an insulated target electrode within the chamber. Positioned in parallel and adjacent relation to the target electrode is a metal plate which supports the work pieces, typically semiconductors, to be covered with the insulating film. Generally, the metal plate is supported by a metal baseplate on metal support legs or the like. An RF power source is arranged to apply an RF potential across the target electrode and metal plate which produces a glow discharge in the region between the target and workpieces. The baseplate and other conductive surfaces of the chamber set the potential of the plasma within the chamber.

The plasma is defined as a field free region in space populated by positive and negative charges.

The technique of RF sputtering allows the deposition of virtually any material in thin film form having essentially the same composition throughout. Of particular interest to the semiconductor industry is the use of such films to provide multilevel insulation in monolithic integrated circuit devices. The manufacture of such devices requires precisely etched holes in insulating films in order to allow interconnection between layers of metallization at different levels. The etching properties of the films are thus of considerable importance.

In the manufacture of multilevel integrated circuit devices, it would frequently be desirable to alter the etch rates of various overlying and underlying films. For example, an underlying film may be etched in undesired areas during etching of an overlying film when precise control of the etching time is not possible or the etch rate is not consistent. A problem experienced with conventionally sputtered films is a tendency to pinhole under chemical attack. For example, in the etching of via holes etchant may reach metal through the very small holes in the layer being etched before the bottoms of the holes actually reach the metal. This results in damage to the metal and in more serious instances to damage to insulation films underlying the metal. Another problem encountered in sputtering insulating films is a tendency of the device to develop "inversion" due to ionic charge pile up. This can have relatively serious consequences on the operation of the device.

In general, the physical properties of sputtered films have been controlled mainly by controlling the gas pressure, the temperature of the substrate, and applied magnetic fields, or combinations thereof, as for example, as disclosed in commonly assigned application Ser. No. 583,175, filed Sept. 30, 1966, now abandoned. Under some conditions, the precise control of these variables are difficult or impractical, and consequently the results obtained are not sufficiently consistent. An additional dimension of control to vary the physical properties of the sputtered films would greatly advance the sputtering technology. This invention provides such an additional control parameter.

SUMMARY OF THE INVENTION

An object of this invention is to provide an improved method for forming thin films by sputter techniques wherein the physical properties of the film can be altered by controlling the film voltage during sputtering.

Another object of this invention is to provide an improved RF-sputtering apparatus capable of controlling the physical properties of the resultant sputtered film.

An object of this invention is to provide an improved sputtering method and RF-sputtering apparatus which makes possible the adjustment of the etch rate of the resultant insulating film.

Another object of this invention is to provide a method and RF-sputtering apparatus which is capable of reducing the tendency of the resultant sputtered insulating film to pinhole under chemical attack.

Still another object of this invention is to provide an improved RF-supttering apparatus which in operation is capable of controlling the substrate voltage magnitude, and also the phase of the substrate holder voltage with respect to cathode voltage.

The aforementioned objects of the invention are achieved by an improvement in an apparatus for RF sputtering which apparatus has a low-pressure ionization chamber, a target holder electrode, a substrate holder and a conductive surface within the chamber, and a source of radio frequency power for producing a glow discharge in the gas in the region between the target electrode and substrate holder electrode by impressing an RF voltage across the respective electrodes. The improvement in the apparatus is the provision of electrically insulating the substrate holder, and connecting an impedance across the substrate holder electrode and the conductive surface. The arrangement provides a means for controlling the RF voltage potential between the substrate holder and conductive surface. The magnitude of the substrate holder voltage and the phase angle of the substrate holder voltage relative to the target voltage can be controlled by varying the impedance, or selecting a suitable value.

The invention provides an additional parameter, and an apparatus embodiment which facilitates its control, for the varying of physical properties of sputtered films. The parameter can be controlled with more precision, and with greater ease, than was possible with the formerly known parameters such as gas pressure, magnetic field, power, etc. The method and apparatus is particularly useful in the fabrication of integrated circuit devices.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention as illustrated in the accompanying drawings:

In the drawings:

FIG. 1 is a schematic view illustrating the general arrangement of the elements and power supply of a typical sputtering apparatus known to the prior art.

FIG. 2 is a schematic view illustrating the general arrangement of the elements and power supply of the invention.

FIG. 3 is a plot of substrate holder impedance versus DC substrate voltage and current depicting various operating conditions of a sputtering apparatus having a given geometry and operating under a given set of conditions.

FIG. 4 is a plot of substrate reactance versus etch rate which illustrates the effect on the etch rate of a deposited SiO_2 film by the varying of the impedance in conformance with the method of the invention.

FIG. 5 is a cross-sectional view of a preferred embodiment of a sputtering apparatus of the invention.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring now to the figures of the drawings there is shown in FIG. 1 a schematic view of a sputtering apparatus 10 and its relationship to the power supply as known to the prior art. The sputtering apparatus 10 has a low-pressure gas ionization chamber 12, typically in the form of a chamber which is mounted on a base plate 14. A suitable inert gas such as argon is introduced into the chamber through an inlet (not shown) and maintained at a low pressure by means of a vacuum pump (also not shown). Within the gas-filled enclosure are positioned a target electrode 16 having mounted thereon a disk 17 of the material to be sputtered, and a substrate holder electrode 18 supported on legs 19. Surrounding the target electrode 16 and insulated therefrom is a shield 20 of conductive material. Substrates 22 are supported on substrate holder electrode 18 mounted on conductive legs 19, in turn joined to baseplate 14. An RF power source 24 is connected to apply an RF potential across the target electrode 16 and substrate holder electrode 18.

The application of an RF voltage to the target electrode in the illustrated sputtering apparatus 10 causes RF currents to flow to the substrate holder 18 and down to the baseplate 14 by way of the metal support legs 19. At the frequency of operation typically (13.56MHz) the impedance of the supporting legs 19 is enough to cause a measurable RF voltage to appear between the substrate holder and the baseplate. The voltage is also affected by the gas pressure, and size and geometry of the electrodes. The potential of the plasma within the chamber 12 is governed by the voltage applied to the conductive surfaces in contact therewith, such as baseplate 14, the conductive sidewalls of the enclosure 12, and the cathode shield 20. These surfaces are normally maintained at ground potential. Thus in the illustrated sputtering apparatus 10 there exists a difference in the potential of the plasma and the substrate electrode holder and substrates thereon. This difference in potential, and also the phase of the substrate holder voltage with respect to the cathode, resulting from the impedance between the substrate holder electrode and the baseplate has been discovered to have a significant effect on the physical characteristics of the dielectric coatings applied by sputtering techniques.

In FIG. 2 there is illustrated schematically the general structure and novel arrangement of the power supply and the elements of the sputtering apparatus of the invention. The sputtering apparatus 30 of the invention has an enclosure 12 mounted on a metal baseplate 14 with a target electrode 16 mounted therein. A target 17 is mounted on target electrode 16 and shielded with a shield 20. The substrate electrode 32 is mounted within enclosure 12 on legs 34 of insulating material which insulates the electrode 32 from the metal base 14. The power supply 24 is arranged to apply an RF voltage potential across target electrode 16 and base plate 14, and also across electrode 16 and substrate holder electrode 32 through an impedance 36. Substrate holder electrode lead 38 is insulated from plate 14 as indicated in FIG. 2. In operation, there is a voltage potential V_s existing between the conductive surfaces in contact with the plasma within enclosure 12 and the substrate holder electrode 32. The capacitive and inductive components of impedance 36 can be varied to control the substrate holder voltage to provide a control over the physical properties of the films applied by the sputtering apparatus 30. This will be explained in more detail in the description that follows.

In any sputtering operation, the active agent is a glow discharge maintained between spaced electrodes in a suitable gaseous medium. In a direct current sputtering operation, the target is a negative electrode or cathode. In an alternating current sputtering operation, the target may be referred to as a "-cathode", even though it is not always negative. Under the influence of the electric field established between the 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 cathode, thereby creating what is known as an "ion sheath" around the cathode. When a glow discharge exists, the region about the cathode which contains this concentration of ions also is known as the "Crookes Dark Space". Within this region the ions are subjected to a high potential which accelerates them toward the cathodes so that they bombard the target with sufficient impact to eject atomic particles therefrom. These ejected or "sputtered" particles of cathode material will be deposited upon nearby objects. The apparatus may be so designed, for example, that the sputtered material will deposit upon articles that are mounted on the opposite electrode or "anode" of the apparatus.

As explained herein above, direct current excitation cannot be successfully employed in the sputtering of an insulating or dielectric material, because when such material is bombarded by positive ions, it will build up a positive charge that repells the ions so they cannot bombard the target with sufficient impact to cause sputtering. Hence it is necessary to employ an alternating current excitation when sputtering a dielectric material in order to discharge the target periodically. Sputtering action takes place during these periods when the target is at a sufficiently negative potential with respect to the glow discharge. During the intervening periods, when the polarities of the electrodes are reversed, electrons are attracted to the target for removing the positive-ion-repellent charge therefrom. Due to the fact that the electrons have greater mobility than the ions, there will be a tendency for more electrons than ions to flow toward the target, but inasmuch as there cannot be any net direct current flowing though a dielectric the target will bias itself negatively in a sufficient amount to prevent direct current from flowing, assuming that the target is the only path which the current can flow between the electrodes.

In order to maintain a glow discharge with a dielectric target or "cathode," the frequency of the applied voltage must be high enough so that the number of ions reaching the target during the negative half-cycle, i.e. when the target electrode is positive and the substrate holder electrode is negative, is not sufficient to neutralize the desired negative charge on the surface of the target. If the target were to acquire substantial positive potential, this would cause reverse sputtering to the object being coated as well as undesirable sputtering of the metal parts associated with the substrate holder electrode which normally functions as the "anode." With the properly selected frequency and magnitude of applied voltage, the sputtering action will be confined to the target, and the anode or substrate holder will not reach its sufficiently high negative potential at any time to produce reverse sputtering or other undesired sputtering effects. Under these conditions, the target being negatively charged most of the time performs a function analogous to that of a cathode in direct current sputtering, and for that reason it may be referred to as the RF cathode, while the opposite electrode is called the RF anode.

With RF voltage applied to target electrode 16, the target 17 functions as the RF cathode during that time in the cycle when the potential of the electrode 16 is negative with respect to ground. During the intervening time the potential of electrode 16 rises above the ground level, thereby attracting electrons to the target for removing the positive charge previously placed on the target by the bombarding ions. As mentioned herein above, electrons are attracted to the target in far greater numbers than the heavier ions but since the target is a dielectric and its electrode 16 is shielded, no net direct current can flow through the RF cathode. Thus, as a result of the interaction of the ions and electrons, the target 17 maintains itself at a generally negative potential with respect to ground, and if it does momentarily require a positive potential, this is not sufficient to reverse the sputtering process or to cause undesired sputtering of any metal parts associated with the RF anode structure **32**.

The improved sputtering apparatus and method of this invention proposes controlling the impedance between the substrate holder and a relatively large conductive surface within the sputtering chamber in contact with the plasma to thereby provide control of the substrate holder voltage magnitude, and of the phase of the substrate holder voltage with respect to the target holder voltage. This general mode of substrate electrode tuning can be used to control the properties of RF-sputtered dielectric films including reactive sputtering. It provides an additional control to supplement the control exerted by varying the pressure, temperature, and magnetic field within the sputtering apparatus which variables are known to the art. Substrate tuning provides an additional dimension of control to the process which can be used to alter the physical properties of sputtered coatings.

The series inductance-capacitance tuning network show in FIG. 5 as variable inductance **74** and capacitor **75**, and in FIG. 2 as impedance **36**, is capable of being varied from a capacitive reactance through a series resonance (0 reactance), to an inductance reactance which can be made to resonate in parallel with the stray capacitance between the substrate holder electrode and ground, i.e. the plate **14** and conductive sidewalls **42** chamber. Thus, the net reactance between substrate holder electrode **32** and ground is continuously variable from zero to a very large inductive or capacitance value. An RF choke **76** is connected to the substrate holder electrode and to a DC meter **78** to measure the DC condition of the substrate holder. Either open circuit DC voltage or short circuit DC current can be measured without disturbing the RF circuit. In a sputtering apparatus in which the impedance between plate **14** and substrate holder electrode is purely inductive, there will be an approximate 180° phase shift between the cathode or target electrode voltage and the substrate holder or anode voltage. Theoretically with such a purely inductive impedance, the cathode voltage will reach its peak positive voltage at the same time as the substrate voltage attains its peak maximum negative voltage. Under such conditions, there will be a maximum DC current flow between the substrate holder electrode and ground since in this condition where the cathode voltage is negative the electrons in the space between the cathode and anode are forced toward the anode while simultaneously the voltage of the anode is positive which results in an attraction of the electrons. This results in a maximum number of electrons collected per cycle by the substrate holder. Conversely, when the impedance is purely capacitive there is approximately a zero degree phase relation between the cathode voltage and the substrate voltage. As such, the cathode voltage and substrate voltage are in step both attaining their most positive and most negative values simultaneously. This results in a minimum DC current between the substrate holder and ground.

Referring now to FIG. 5, there is depicted a preferred specific embodiment **40** of the sputtering apparatus of the invention. It is understood that FIG. 5 does not necessarily depict the relative dimensions of the various elements of the apparatus, since some are depicted schematically. Apparatus **40** has a metal baseplate **14** having mounted thereon a cylindrical enclosure **42** with a top plate **44** supported thereon. Annular seals **45** are provided to insure a tight seal between the base plate **14**, cylindrical wall **42**, and top plate **44**. A vacuum pump **46** communicates with the interior of apparatus **40** shown schematically in FIG. 5. Also provided is an inlet **48** for introducing gas within the chamber of apparatus **40** with a valve **49** to control the flow of gas. Mounted within the chamber is a target electrode **16** supporting target **17** thereon. Target electrode **16** is provided with a heat-exchange means to control the temperature. Cooling fluid is circulated through the annular opening formed between electrode terminal **51** and concentric tube **21** and tube **21**. As indicated by the arrows, cooling fluid is introduced in the aforementioned annular opening, circulated within the target electrode **16** and subsequently withdrawn through outlet tube **51**. As indicated in FIG. 5, target electrode **16** is insulated from plate **44** with an insulating sleeve **52** of glass, ceramic or a suitable plastic or other suitable insulating material. A shield **20** is provided which surrounds the target electrode **16** to prevent erosion of the electrode by the sputtering action. This shield is described and claimed in commonly assigned patent application Ser. No. 428,733, filed Jan. 28, 1965.

A substrate holder electrode is positioned opposite the target **17** within the chamber of the sputtering apparatus. Substrate holder electrode consists of a conductive plate **32** supported on legs **34** of insulating material. Substrates **60** are mounted on an insert plate **62** seated in a recess in plate **32**. An electrode and cooling coil **64** makes electrical contact with plate **32** and also provides a means to control the temperature of the plate and substrates. Coil **64** is introduced within the chamber through an insulating seal **66** in the bottom of plate **14**. The temperature of the substrate holder electrode is maintained by circulating water or other liquid through coil **64** as indicated by the arrows on the drawing.

A RF power source **70** is electrically connected to the target electrode **16** to apply an RF voltage potential across the target electrode **16**. A suitable impedance-matching circuit is illustrated schematically in the drawing. It consists of a variable capacitor **71**, an inductance **72**, and second variable capacitor **73** connected across the power source to plate **44**, which circuit provides a means of compensating for the impedance of the power supply conduit to maintain the desired phase of the voltage and current delivered to the target electrode. An impedance consisting of a variable inductance **74** and a capacitor **75** is connected across ground baseplate **14** and the substrate electrode holder. This impedance provides a new degree of control to be applied when sputtering dielectric films on substrates.

In order to monitor the DC substrate holder voltage or current, a shunt inductance **76** in series with a DC meter **78** is connected across ground and the substrate electrode holder. This arrangement, including the impedance having the variable inductor element **74** and capacitor **75**, enables the application and control of an RF voltage potential to be applied to substrates being sputtered.

This condition creates a negative DC potential on the surface of the deposited insulator film which attracts positive impurity ions in the insulator film to the surface of the film. This attraction of the impurity ions has the effect of physically removing them from the semiconductor body-insulating film interface thus eliminating the inversion phenomenon.

The method and apparatus can also be used to control the amounts of sputtering gas trapped in the film. An example where such may be useful is the varying of the electrical resistivity of a sputtered metal film since resistivity is influenced by trapped gases.

In order to better understand the invention, the following examples are set forth to show the manner in which the apparatus and method can be employed.

EXAMPLE I

With a sputtering apparatus similar to the depicted in FIG. 5, silicon wafers were loaded on the substrate electrode holder, which was 9 inches in diameter, a silica target with a diameter of 6 inches was mounted on the target holder electrode, and RF power of 500 watts applied. The target substrate holder spacing was 1.25 inches. The pressure Voltage maintained at 15 millitorr. A number of runs were made in which the substrate reactance was varied by changing variable impedance **74**. At each variation, the open circuit DC voltage and the short circuit DC current was measured with DC meter **78**. The results are given in the following table and also shown in FIG. 3, of the drawing. Curve **82** depicts open circuit voltage and curve **84** depicts short circuit current.

Table I

Substrate Voltage Ohms	DC Open Circuit Voltage (Volts)	DC Short Circuit Current (ma)
−16	+10v	+0.6
−5	0	0
+4.5	−7v	−1.0
+12	−15	−2.4
+24	−33	−5.5
+37	−35	−5.5
+40	+2	+0.04
+60	+5	+0.12

This illustrates the correlation between substrate reactance and DC substrate voltage and DC substrate current. The portions of the curves **83** and **85** depict narrow ranges of instability. The reason for the instability ranges is not known at present.

EXAMPLE II

Silicon dioxide coatings were applied to silicon wafers using a sputtering apparatus generally similar to the one depicted in FIG. 5 and described in example I. The wafers were polished, cleaned and dried in the conventional manner and placed on the substrate holder electrode. The chamber was closed and argon gas introduced and maintained at a pressure of 15 millitorr.

A total of seven runs were made in which SiO_2 films were applied to silicon wafers. In all of the runs, the power was held constant at 500 watts for a duration of 30 minutes.

The net substrate holder reactance was different for each run varying from −16 to +27 ohms. The net reactance represented the combination of the stray impedance from the apparatus and the reactance of the variable impedance. During each of the runs, the DC substrate current was read directly from DC meter **78**.

The pinhole breakup thickness of each of the films was measured by the following technique. A plurality of areas were etched in each wafer which extended partially through the films to different depths which depths were measured. The wafer was then placed in a copper electric plating bath for a period of sufficient duration to allow copper to plate out on any exposed area. The wafers were then examined under a microscope. A high density deposit in an etched area indicated a pinhole breakup.

The trapped argon in the sputtered films on each wafer was measured by X-ray florescence techniques.

The results of the aforementioned tests are given in the following table. The results of the etch rates of the films are also depicted graphically in FIG. 4.

TABLE II

Substrate reactance Xohms	DC substrate holder current (ma.)	P etch rate, A./sec.	Pinhole break-up thickness (percent of total thickness)	Estimated mole percent trapped argon
+27	−5.5	5.2	12	2.5
+20	−5.0	5.8	4	
+12	−2.4	4.8	5	1.2
+8.2	−2.0	5.5	16	
+4.5	−1.0	9.9	62	0.5
−3.5	0	9.4	69	0.4
−16	+0.6	10.2	85	0.8

At the termination of the runs, the wafers were subjected for a given time interval to an etchant consisting of 10 parts (by volume)HNO_3 (70 percent solution); 15 parts (by volume) HF (49 percent solution); 300 parts (by volume) H_2O, for a given time interval. The depth of the etch was measured and the etch rate calculated. The above table and FIG. 4 both illustrate the profound influence of substrate reactance on the etch rate, pinhole breakup thickness, and percent of trapped argon.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.

I claim:

1. In an apparatus for RF sputtering, a low-pressure ionization chamber, a target holder electrode, a target of dielectric material supported on the target holder electrode, a workpiece holder electrode, and a third electrode comprising at least a conductive surface, and a source of RF power arranged to impose an RF voltage across the target holder electrode and the third electrode to produce a glow discharge in the region between the target holder electrode and the workpiece holder electrode, the improvement comprising:

means for electrically insulating said third electrode from said target holder electrode and said workpiece holder electrode,

impedance means electrically connected directly between said workpiece holder electrode and said third electrode, said impedance means to provide a control of the relative RF voltage between the workpiece holder electrode and the third electrode.

2. The apparatus of claim **1** wherein the source of RF power is arranged with a first terminal in electrical contact with said target holder electrode, a second terminal of opposite polarity in electrical contact with said third electrode, and said substrate holder in electrical contact with said second terminal through said impedance means,

the resultant apparatus in use adapted to provide a control for the substrate holder voltage magnitude and for the phase angle of the substrate voltage with respect to target holder electrode voltage.

3. The apparatus of claim **2** further including a means to monitor the DC voltage potential between said workpiece holder electrode and said third electrode.

4. The apparatus of claim **1** wherein said impedance means includes a variable inductance.

5. The apparatus of claim **1** wherein said impedance means includes a variable capacitance.

6. The apparatus of claim **1** wherein said third electrode includes a metal baseplate positioned adjacent and beneath said workpiece holder electrode.

7. The apparatus of claim **6** wherein said third electrode further includes metal sidewalls of said chamber.

8. The apparatus of claim **7** wherein said third electrode further includes a metal top plate for said chamber.

9. The apparatus of claim **8** wherein said third electrode further includes shield means for said workpiece holder electrode.

10. In a method for sputtering a dielectric material by RF-stimulated glow discharge whereby power from an RF power source is impressed across a target electrode associated with a source of material, and the combination of a substrate holder electrode supporting workpieces to be coated and a conductive surface insulated from said target electrode and substrate holder electrode and in contact with the resultant generated plasma in the environment of the target electrode and substrate holder electrode, the improvement comprising,

imposing an impedance between said substrate holder electrode and said conductive surface, adjusting the impedance to vary the substrate holder RF voltage magnitude, and the phase of the substrate holder voltage with respect to the target electrode.

11. The method of claim **10** wherein net impedance of the imposed impedance and the stray impedance of the apparatus is essentially an inductive reactance.

12. The method of claim **1** wherein the inversion characteristics of the sputtered film are controlled by DC grounding the substrate holder.

* * * * *