RF SPUTTERING OF INSULATOR MATERIALS

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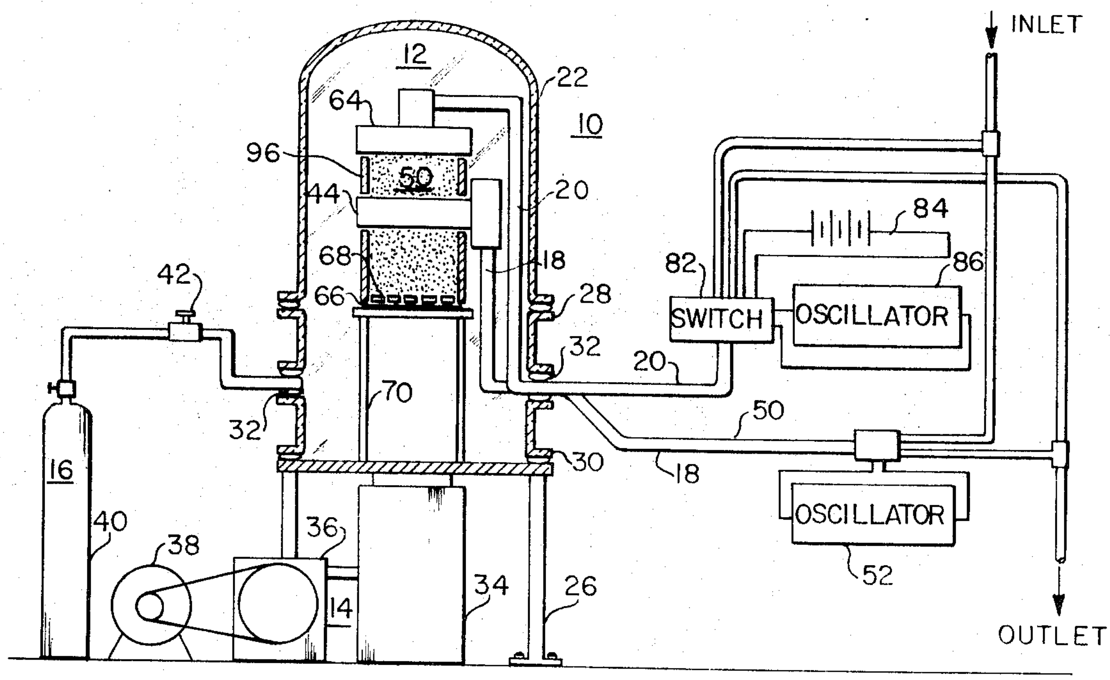

FIG-1

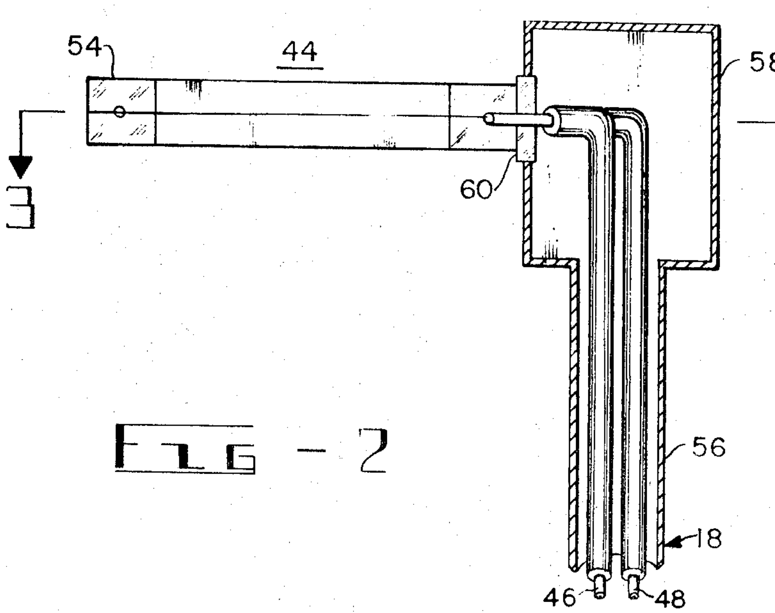

FIG-2

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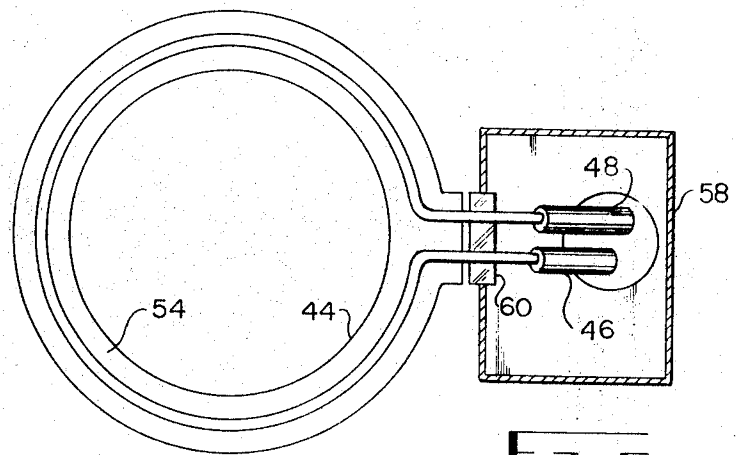

FIG-3

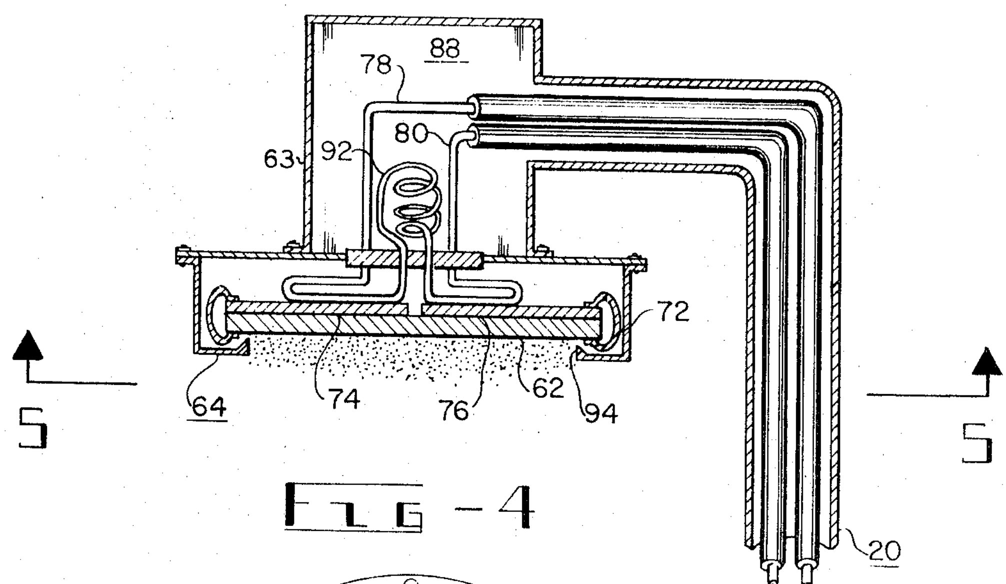

FIG-4

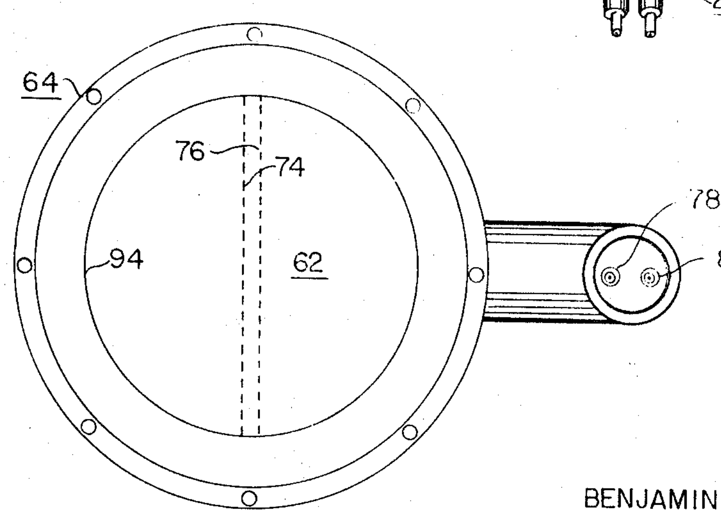

FIG-5

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RF SPUTTERING OF INSULATOR MATERIALS

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ABSTRACT OF THE DISCLOSURE

Method and apparatus for sputtering electrically nonconductive material wherein potentials of opposite polarities are applied to a target of nonconductive material which polarities are alternated at (RF) radio frequencies. The sputtering discharge may also be supported by RF potentials.

In the physical process of sputtering, atoms are ejected from a surface under positive ion bombardment. The positive ions, being formed by electrons colliding with gas molecules, bombard the cathode or target and atoms of the target material are ejected. The atoms are ejected by the direct momentum transfer of energy from the positive ion to the ejected atom resulting in high velocity atoms produced by the kinetic energy released through the ion bombardment. The target material must be kept at a potential that is negative relative to the positive ions to draw the positive charge ions for bombardment. Where the target material is a conductor; then the positive potential accumulated on the surface because of the positive ions impacting against the target is drained off by the negative direct current power source. However, where the target material is a non-conductor, then the positive ions depositing on the surface to create sputtering will accumulate sufficiently to eventually create a positive charge that repels or inhibits further sputtering.

In conventional sputtering devices the plasma is produced by auxiliary alternating or static magnetic or electrical fields. These fields must be closely related to and coordinated with the entire sputtering process and the target or cathode potential. The ejected atoms travel through a substantially direct path to impact on surrounding structure, walls and fittings. Some of the ejected atoms return to the target itself after having collided with gas molecules, however a sufficient portion of the ejected atoms are deposited on a selected surface. In such conventional sputtering processes, the sputtered atoms may not be pure because contaminating atoms from surrounding walls and fixtures or from contaminating gases can be mixed with the ejected atoms and thus the deposited material. For applications that require a pure film, such as in space electronics, it is necessary to preform the process in a vacuum and to reduce sputtering of surrounding walls and fixtures as much as possible. However, the sputtering of surrounding walls and fittings is not entirely prevented is not entirely prevented in such sputtering processes and adversely affects the thin film produced on the selected surface.

It is therefore an object or our invention to provide a novel and improved method and apparatus for producing thin films.

It is another object of our invention to provide a novel and improved method and apparatus for producing thin films by sputtering.

It is another object of our invention to provide a novel and improved method and apparatus for producing thin films by sputtering in a plasma produced by radio frequency induction that is independent of the sputtering process itself.

It is another object of our invention to provide a novel

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and improved method and apparatus for producing thin films by sputtering in a high density plasma in which the plasma is produced by a high frequency magnetic field without the need for any auxiliary alternating of static magnetic or electrical fields.

It is another object of our invention to provide a novel and improved method and apparatus for producing thin films in which power is supplied to the target by means of a single stage power oscillator means, the frequency of which adjusts itself to various loading conditions and obviates the need for separate tuning adjustments.

It is another object of our invention to provide a novel and improved method and apparatus for producing thin films which apparatus can use highly reactive as well as inert (noble) gases without harm to the electrodes.

It is another object of our invention to provide a novel and improved method and apparatus for producing thin films that uses a separate induction coil for the creation of the plasma and which coil is insulated and shielded from the plasma.

It is another object of our invention to provide a novel and improved method and apparatus for producing thin films that is simple and inexpensive to construct and is easy

It is another object of our invention to provide a novel and improved method and apparatus for producing thin films that is simple and inexpesive to construct and is easy to operate.

The present invention comprises a vacuum chamber that is evacuated by a pump. A gas supply means supplies gas to the chamber at a low but constant pressure. A shielded and cooled induction coil is positioned in the chamber and is supplied with high frequency current. The induction coil generates a high frequency magnetic field in its central volume that produces an accompanying high frequency electric field for generating plasma. The shielding prevents unwanted radiation of electromagnetic energy. High frequency power for the induction coil is supplied by a single stage oscillator that tunes itself automatically to match all loading conditions and obviates the need for complex tuning adjustments.

The target to be sputtered is supported by a target holder that includes a pair of electrodes. If the target material is a conductor, then direct current that is negative to the potential of the plasma and surrounding structures is applied to the target through the electrodes. If the target is a nonconductor, then high frequency alternating current is applied to the two electrodes in such a manner that the instantaneous potentials of the two electrodes are 180 degrees out of phase. Thus separate portions of the nonconductor will be sputtered at separate intervals, that is, when the particular backing electrode is negative.

Ion bombardment during the interval of sputtering deposits a positive charge on the surface of the non-conducting target. During this interval the other electrode is positive and the surface of the non-conducting target adjacent said other electrode attracts electrons out of the plasma. This effectively neutralizes the positive charge acquired during the previous cycle. Thus during such sputtering of non-conductors, one of the target holder electrodes is always positive, drawing electrons out of the plasma to the surface of the non-conducting target, while the other electrode is negative by an equal but opposite amount, drawing ions out of the same plasma to the non-conducting target surface. This insures that the next potential of the plasma with respect to surrounding fixtures remains zero, thereby avoiding the inhibiting of sputtering of the target and reducing unwanted sputtering of adjacent structures.

Other features and advantages of the present invention will become more apparent from the following detailed description taken in conjunction with the accompanying drawings which illustrates and clarifies the preferred embodiment of this apparatus, and in which:

FIG. 1 is a representative view of our invention for producing thin films by sputtering.

FIG. 2 is a cross section of the insulated and shielded high frequency induction coil assembly that produces the high density plasma.

FIG. 3 is a sectional view of the induction coil assembly taken from FIG. 2 along line **3—3**.

FIG. 4 is a sectional view of the electrode target holder assembly and shielded electrical supply line structure.

FIG. 5 is a sectional view of the electrode target holder assembly taken from FIG. 4 along line **5—5**.

Referring now to the drawing wherein like reference characters designate corresponding parts throughout FIGS. 1 through 5; there is shown in FIG. 1 a thin film production apparatus **10** including a thin film sputtering unit **12**. The sputtering unit **12** comprises a vacuum chamber or enclosed container **22**, such as a glass "Pyrex" bell jar, that is supported by support means **26**. Positioned between support means **26** and container **22** are section rings **28** and **30** that have flanges and seal means **32** for providing a vacuum tight access through which the gas supply means **16** and the cooling fluid supply means **18** and **20** pass. A vacuum pump means **14** that comprises a diffusion pump **34** in combination with a roughing pump **36** is driven by a motor **38**. The vacuum pump means **14** continuously removes impurities, such as contamination and condensation particles and gases, from container **22** during operation of the thin film production apparatus **10**.

A gas, stored in a container **40**, is continuously and slowly released into the bell jar **22** through a throttling valve **42**. This throttling valve **42** is selectively adjusted so that a low but constant gas pressure is maintained in the bell jar **22** (for example, about 0.0005 millimeter of mercury absolute). An induction coil **44** is located within the bell jar **22** and is supplied with high frequency current through lines **46** and **48**. Cooling fluid for cooling the conductors in line **18**, such as water or compressed air, is carried in tubular insulated conductors **46** and **48**. A shielding structure **56** entirely encloses the conductors **46** and **48** and prevents unwanted radiation of electromagnetic energy in the enclosed container **22**.

Induction coil **44**, when energized with high frequency current, generates a high frequency magnetic field in the volume in and near its hollow center that produces an accompanying high freqeuncy electric field. This electric field ionizes the low pressure gas in the volume to produce plasma. The high frequency power for induction coil **44** is supplied by the high frequency generator **52**, which comprises a single stage power oscillator that tunes automatically to match all loading conditions and thereby eliminates the need for complex tuning adjustments. The coil **44** is enclosed in the ring shaped ceramic shielding member **54** in container **22**. Line **18** encloses the length of the conductors **46** and **48** that connect the generator **52** with the coil **44**. Line **18** also shields conductors **46** and **48** to the junction box **58** that is connected to the ceramic members. A ceramic sealing disc **60** is provided at the junction box **58** for vacuum tight sealing of the conduit conductors **46** and **48** that pass therethrough.

The target **62** that is sputtered (see FIGS. 4 and 5), is supported by a target holder means **63**. The target **62** is in the plasma **50** even though the target is spaced above coil **44**. The target **62** is positioned parallel to and along the axis of the opening through the center of coil **44**. Particles dislodged by sputtering from the target material **62** will travel through the opening of coil **44** toward the substrate **66**. In order to form a desired pattern on the substrate **66**, a mask **68** is positioned between target **62** and the substrate **66** so that the particles will travel through the openings of the mask **68** and impact and adhere to the substrate **66** forming a thin film pattern on its surface. The substrate and mask **66** and **68** are supported by a support means **70** that is secured in the container **22** above the diffusion pump **34**.

The target holding means **63** is provided with holding devices or clips **72** and a pair of half circular shaped electrodes **74** and **76**. The clips **72** hold the target **62** securely against the electrodes **74** and **76** and the electrodes **74** and **76** are connected to an electrical power source by tubular insulated conductors **78** and **80** which also provide partial support for the electrodes. A cylinderical housing **20** shields the electrical conductors **78** and **80** and prevents unwanted radiation of the electromagnetic energy carried by the conductors. A switching means **82** functions to selectively supply direct current from source **84** or alternating current from source **86** to conductors **78** and **80**. Thus the electrodes **74** and **76** are either supplied alternating current or direct current, depending upon the position of the switch **82**.

The conductor **78** is shaped into an induction coil **92** after its electrical contact with electrode **74**. The tubular coil **92** completes the cooling fluid circuit while presenting a high impedance to high frequency currents. A shroud **94** shields the clips **72** and the other side of the electrodes **74** and **76** from the plasma **50** and prevents unwanted sputtering of walls and fixtures. The half circular shaped electrodes **74** and **76** are separated by a small distance across the diameter of the half circle. For guidance of the sputtered atoms and confinement of the plasma, a shielding means **96** and **97** is secured between the target holding means **64**, the coil **44** and the support **70**.

OPERATION

In operation, the thin film sputtering unit **12** of the thin film production apparatus **10** receives a continuous supply of gas during operation. The bell jar **22** is evacuated by the vacuum pumping means **14** and the gas that enters the jar **22** at a predetermined rate may be any gas suitable for creating ions in a plasma, for example, argon or the like. The gas in passing through the jar **22** absorbs impurities such as moisture, unwanted gases, contamination or molecular particles or the like from the inside of the jar **22** and its associated structures. The continuous admission of new gas and the continuous removal of old gas creates a pure, low pressure gaseous condition within the jar **22**. The diffusion pump **34** may be any conventional type, such as an oil or mercury diffusion pump system. The low pressure gas admitted into the evacuated jar **22** quickly diffuses to all parts of the jar **22** and is ionized by the high frequency magnetic field produced by induction coil **44**.

The high frequency electrical conductors **46** and **48** and **78** and **80** carry current to the jar **22** and are provided with pressurized fluid means, such as air or water through the hollow conductors, for cooling. As shown in FIG. 1 a water supply inlet is connected through switch **82**, and circulates cooling water through the electrical conductors to a combined outlet.

While any type of suitable material can be sputtered in the present thin film production apparatus **10**, such as conductive and nonconductive materials, the mode of operation for sputtering conductive or non-conductive materials is different. Assuming that the target material is a conductor, as for example, copper, gold, silver, etc., and the inside gaseous pressure environment of the container **22** is at its desired value; switch **82** is set to apply a direct current to the electrodes **74** and **76**. The direct current has a constant negative potential with respect to the plasma and the surrounding structures. The positive ions which are formed in the plasma are attracted to the now negative electrodes **74** and **76** and bombard the target material **62** causing sputtering. The sputtered particles or atoms are ejected from the target **62** as described hereinbefore, and travel through the opening in the induction coil **44** towards the substrate **66**. A mask **68**, having a predesigned pattern screens the substrate **66** and forms a thin film with a predetermined pattern on the substrate **66**. The negative potential source removes the positive charges deposited on the target material.

When the target material **62** is of a non-conducting material, as for instance ceramic or the like, a high frequency current is then applied to the electrodes **74** and **76** by the setting of the switch **82** in the proper high frequency position. The electrodes **74** and **76** are now supplied with instantaneous opposite potentials that are 180 degrees out of phase. This phase shifting is caused by the balanced output of oscillator **86** and aided by the impedance of tubular coil **92** to the applied high frequency current. Thus at any instance, one-half of the material **62** is negative and is thus sputtered while the other half of the non-conducting material is positive and repels bombarment of the positive ions. Ion bombardment during this interval of sputtering deposits a positive charge on the negative one-half surface of the non-conducting target **62** that is sputtered. In order that this positive charge does not subsequently repel and inhibit further sputtering, the opposite electrode that was previously sputtered is positive and attracts electrons sputtered from the other half of the target. This effectively neutralizes the positive charge acquired previously. Thus, during the sputtering of non-conductors, one of the electrodes is always positive and draws electrons out of the plasma **50** to the surface of the non-conductor material of the target, while the other electrode has a negative potential that draws ions out of the same plasma and causes the non-conducting target to be sputtered. This action insures that the potential of the plasma with respect to surrounding fixtures and structures remains zero, and thus reduces the unwanted sputtering of adjacent structures and/or fixtures.

It should be understood to anyone familiar with the art that the vacuum pumping means, the gas supply means and its associated components as shown herein can be replaced by any other vacuum or pumping means producing an equal result.

We claim:

1. In a sputtering apparatus, including a vacuum chamber,

means for admitting an ionizable gas into said chamber,
means for effecting an electrical sputtering discharge within said chamber,
target holding means for supporting an insulator material in said sputtering discharge to be sputtered,
wherein said insulator material is positioned so that a surface thereof comes into contact with said sputtering discharge,
means for applying RF potentials to said target to cause said insulator material to sputter;
the improvement wherein said means for applying a RF potential includes means for simultaneously impressing a first polarity current on a first electrode adjacent one portion of said surface and an opposite polarity current on a second electrode adjacent another portion of said surface and alternating said polarities at RF.

2. In a sputtering apparatus as claimed in claim **1** wherein

said means for applying a RF potential includes electrode means that include said first and second electrodes for conducting alternating RF current,
said electrode means includes means for reversing the phase of the alternating RF current in the other electrode relative to the phase of the alternating RF current in the other electrode to cause each of said electrodes and space charges adjacent said respective surfaces of said insulator material to simultaneously have opposite polarities.

3. In a sputtering apparatus as claimed in claim **2** including,

said first and second electrodes are electrically connected by an induction coil.

4. In a sputtering apparatus as claimed in claim **3** in which,

said insulator material has flat surface portions on its side opposite the surface presented to said sputtering discharge,
and said first electrode contacts a first conductor plate that is positioned immediately adjacent said opposite flat surface in an area corresponding to said one portion of said surface and said second electrode contacts a second conductor plate that is positioned immediately adjacent said opposite flat surface in an area corresponding to said another portion of said surface.

5. In a sputtering apparatus as claimed in claim **4** in which,

said conductor plates abut against said flat surfaces,
said induction coil comprises a coil that is connected between and in series with said first and second electrodes,
and said induction coil forms an inductive impedance between said electrodes of sufficient magnitude to substantially reverse the phase of the alternating RF current from one electrode to the other electrode.

6. In a sputtering apparatus as claimed in claim **4** including,

a housing positioned within said container that completely encloses said electrodes and conductor plates from said sputtering discharge.

7. In a sputtering apparatus as claimed in claim **1** including,

RF induction means for ionizing said gas into said sputtering discharge,
a first RF current source for supplying high frequency current to said means for applying a RF potential,
and a second RF current source for supplying high frequency current to said RF induction means.

8. A method of sputtering in a vacuum chamber comprising the steps of,

admitting an ionizable gas into said chamber,
effecting a sputtering discharge in said chamber,
positioning an insulator material so as to contact said sputtering discharge to sputter the surface of said insulator material,
simultaneously applying a first polarity current through an electrode adjacent one portion of the surface of the insulator material and a second polarity current through a second electrode adjacent another portion of the surface of the insulator material,
and alternating said polarities at RF.

9. A method of sputtering as claimed in claim **8** in which,

the opposite potential polarities are provided by RF alternating current that is phase shifted between the portions of the nonconductive material.

10. A method of sputtering as claimed in claim **8** in which

said sputtering discharge is produced by applying RF alternating current excitation to the interior of the container.

11. A method of sputtering as claimed in claim **8** including the steps of,

providing a continuous controlled flow of a given gas to said evacuated container during sputtering,
and continuously evacuating said given gas from said container during sputtering.

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U.S. Cl. X.R.

204—298