March 12, 1974 L. T. LAMONT, JR., ET AL 3,796,649

COAXIAL SPUTTERING APPARATUS

Filed Dec. 13, 1971 2 Sheets-Sheet 1

FIG. 1

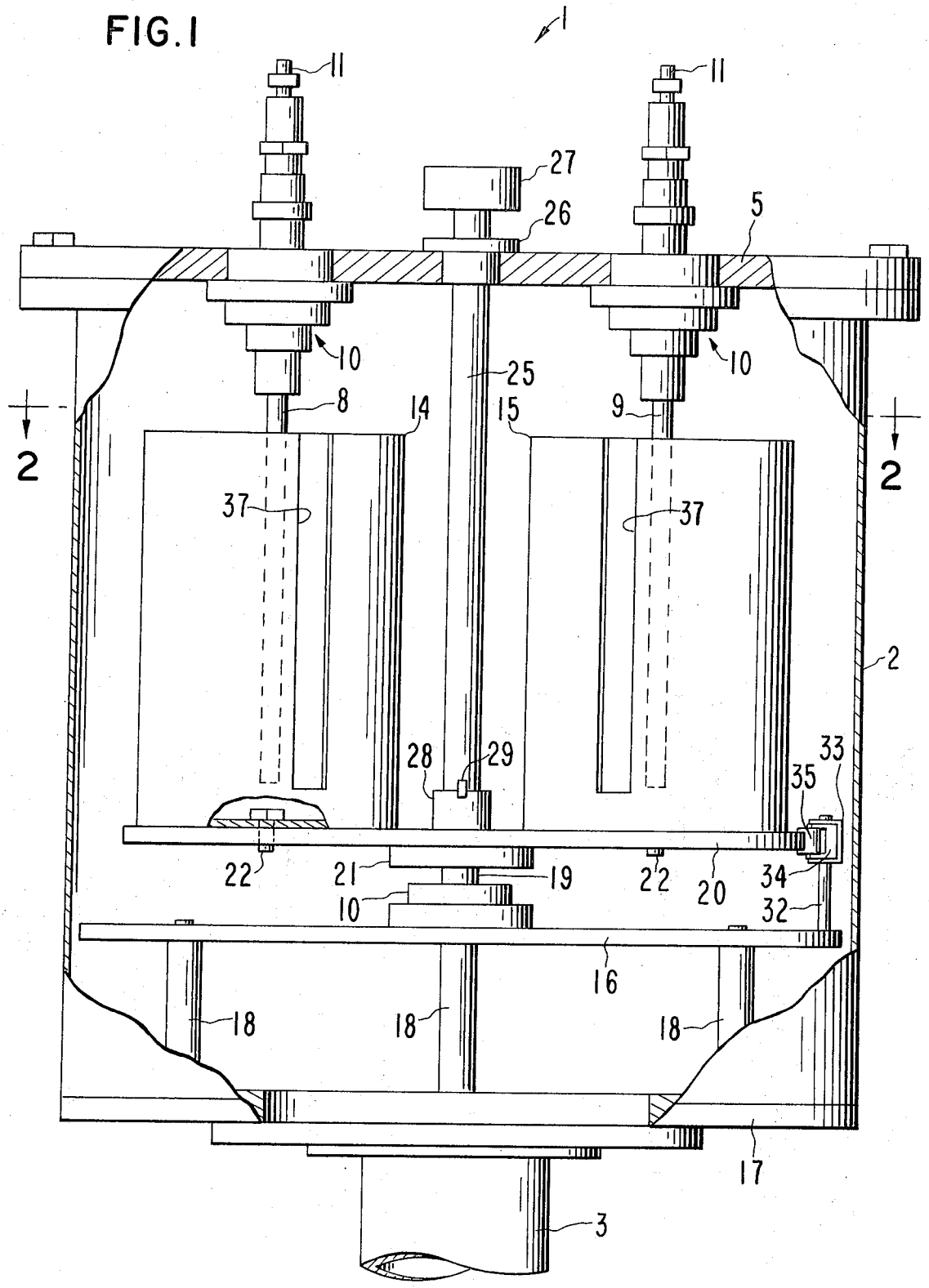
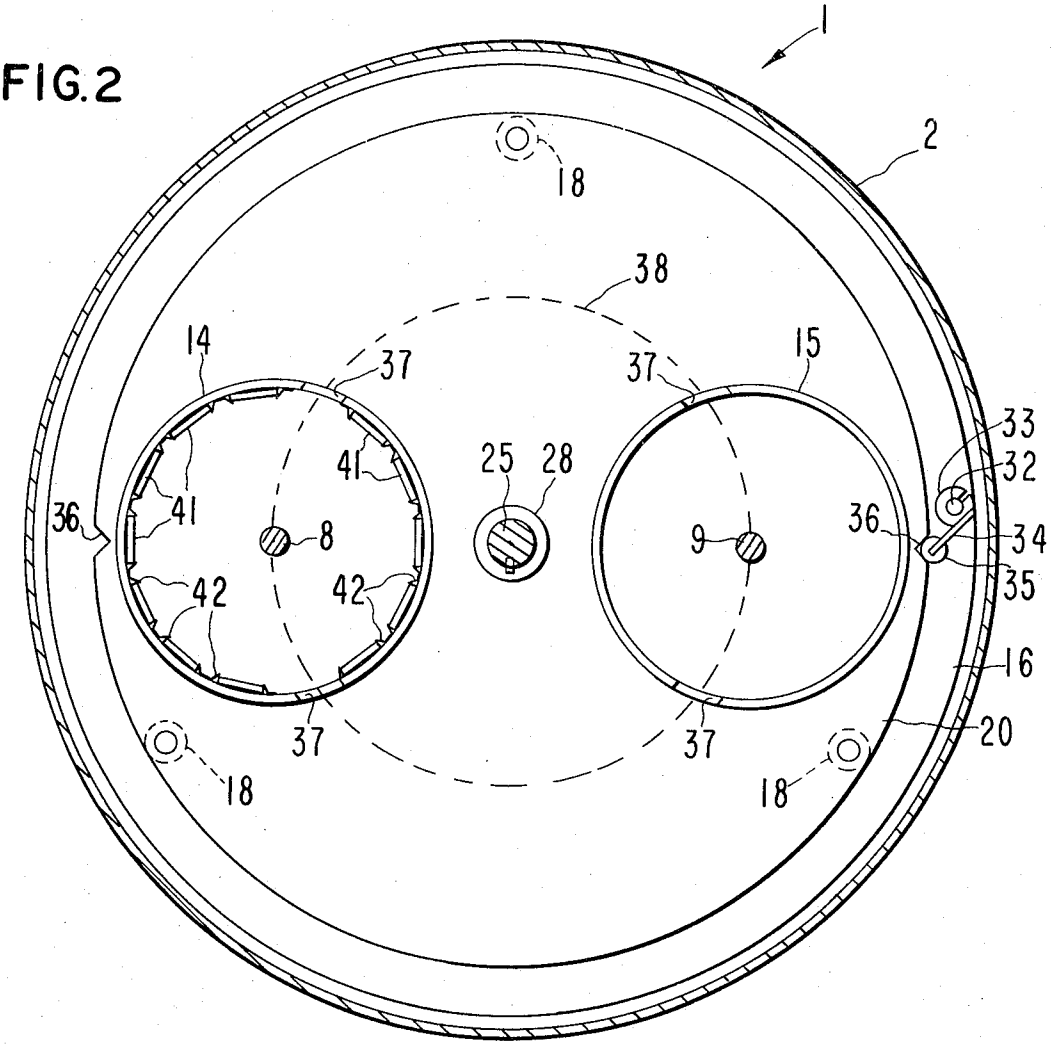


FIG.2



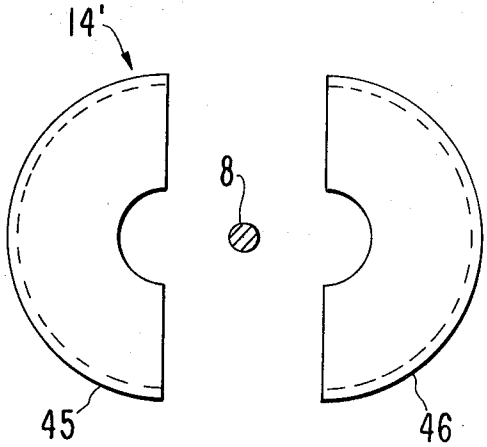


FIG.3A

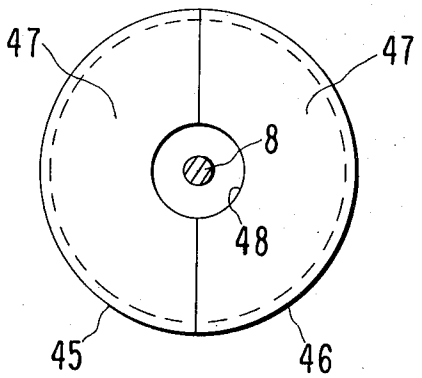


FIG.3B

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3,796,649

COAXIAL SPUTTERING APPARATUS

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U.S. Cl. 204—298 15 Claims

ABSTRACT OF THE DISCLOSURE

This invention provides sequential sputter-coating of materials from different targets onto a desired number of substrates during a single pump-down cycle of the sputtering apparatus. The substrates are detachably affixed to the inside surface of a hollow cylinder. The cylinder is mounted upon a rotatable table so that the axis of the cylinder is parallel to the axis of rotation of the table. A plurality of target electrodes extending downward toward the rotatable table are mounted above the table at locations concentric around the axis of rotation of the table and spaced from the axis of rotation by a distance equal to the distance from the axis of rotation of the table to the axis of the cylinder. Vertical slits are provided in the hollow cylinder from the top edge of the cylinder downward toward the rotatable table. The dimensions of the slits are such that as the table is rotated the substrate-containing cylinder does not come into contact with any of the target electrodes, yet at selected positions in the course of the table's rotation the cylinder envelops in sequence within its volume each one of the target electrodes. Sputtering occurs only when a target electrode is enveloped by the substrate-containing cylinder, and this sputtering takes place in the region within the cylinder. After coating from a particular target has been completed, the table is rotated to bring the cylinder to a new position where it will envelop a different target. Sputtering is then allowed to occur at this new position to produce a lamina of this different coating material. The process may be repeated for a number of target electrodes. It is also possible to provide a plurality of substrate-containing cylinders mounted concentrically on the table about its axis of rotation. Because sputtering takes place within the substrate-containing cylinder and occurs only when a sputter target is enveloped by the cylinder, the likelihood of contamination of the coating laminae by material sputtered from other parts of the sputtering apparatus is minimized.

BACKGROUND OF THE INVENTION

(1) Field of the invention

This invention is a further development in the field of sputter-coating, particularly in the technique of sequentially coating a substrate during a single pump-down cycle with materials sputtered from different targets.

(2) Description of the prior art

A sputtering apparatus for sequentially coating a substrate during a single pump-down cycle with material sputtered from different targets is disclosed in copending patent application No. 20,446, filed Mar. 23, 1970 by Lawrence F. Herte and Frank R. Kloss, now abandoned, which is assigned to Varian Associates, assignee of the instant patent application. The increasingly sophisticated applications in conventional and cryogenic electronics of thin films, especially of laminated films of different materials, demand that techniques be developed to produce sequentially deposited thin films of maximum purity. In prior-art sputtering apparatuses, the most significant source of film contamination is the sputtering of undesired material from apparatus components other than the intended sputter target. Techniques heretofore developed

to minimize contamination of the sputter coating have generally involved some type of shutter or shield arrangement applied to a planar type of sputtering apparatus.

SUMMARY OF THE INVENTION

It is the primary object of this invention to provide a sequential sputtering apparatus with multiple targets wherein the substrate is optimally shielded and the plasma which causes the sputtering is confined to the region between the sputter target and the substrate in order to minimize contamination of the sputter coating, particularly in a coaxial sputtering apparatus.

In the preferred embodiment, the substrates are detachably affixed to the inside surface of hollow cylinders. The cylinders are mounted upon a rotatable table so that the axes of the cylinders are parallel to and equi-distant from the axis of rotation of the table. A plurality of target electrodes extending downward toward the rotatable table are mounted above the table at locations concentric around the axis of rotation of the table, with their axes spaced from the axis of rotation by a distance equal to the distance from the axis of rotation of the table to the axes of the cylinders. Vertical slits are provided in the hollow cylinders from the top edge of the cylinders downward toward the rotatable table. The dimensions of the slits are such that as the table is rotated the substrate-containing cylinders do not come into contact with any of the target electrodes, yet at selected positions in the course of the table's rotation the cylinders envelop in sequence one of the target electrodes. The rotatable table and the target electrodes are mounted within a vacuum chamber. Means are provided for evacuating the chamber and for introducing into the evacuated chamber a quantity of ionizable gas such as argon. Controls are provided outside the vacuum chamber for rotating the table. Means are also provided for applying a radio-frequency voltage to a target electrode when the electrode is enveloped by a substrate-containing cylinder. This voltage will induce a radio-frequency excited gas discharge within the cylinder. The cylinders are electrically grounded, whereas an energized target electrode alternatively assumes positive and negative potentials different from ground potential. In the presence of the plasma generated by the radio-frequency signal, the target electrode assumes a negative self-bias direct current potential superimposed upon the radio-frequency alternating current potential. This self-bias potential is attributed to the higher mobility of the electrons relative to the positive ions in the plasma. Thus, more electrons are attracted to the target electrode during the positive half-cycle of the radio-frequency voltage than there are positive ions attracted to the target electrode during the negative half-cycle. This results in a net accumulation of electrons on the target electrode averaged over the entire radio-frequency cycle, thereby producing a negative self-bias potential on the target electrode. Positive ions from the plasma are accelerated to the target electrode by the negative self-bias potential of the target electrode.

Positive ions, in striking the target electrode, physically sputter atoms of material from the electrode. This sputtered material condenses upon the substrates that are supported on the inside surface of the substrate-containing cylinder, thereby sputter-coating the substrates. The configuration of the substrate-containing cylinder minimizes the occurrence of sputtering onto substrates within the cylinder from apparatus components other than from the target electrode which is confined within the substrate-containing cylinder.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevational view, primarily in cross-section, showing the preferred embodiment of this invention;

FIG. 2 is a cross-sectional view taken on line 2—2 of FIG. 1; and

FIGS. 3A and 3B are schematic top views of an alternative construction of the substrate-containing cylinders.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, the sputtering apparatus of the invention is indicated generally by the reference number **1**. The apparatus comprises a vacuum-tight chamber **2** and conventional means (not shown) connected to a pipe **3** for evacuating chamber **2** and introducing ionizable gas such as argon into the chamber. Chamber **2** is fitted at the top with a vacuum-sealed detachable cover plate **5**. Target electrodes are supported from the cover plate and extend vertically downwardly into chamber **2**. In the drawings, two such target electrodes **8** and **9** are shown. The target electrodes are supported by feed-through elements **10** sealed vacuum-tight in the cover **5**. The target electrodes are adapted to be supplied with electrical energy through terminals **11**.

Cylindrical substrate containers are mounted in the chamber as will now be described. In the drawings two such containers **14** and **15** are shown. The object of the invention is to provide for movement of the target electrodes and substrate containers in a manner which will permit the target electrodes to be selectively inserted into and removed from each of the substrate containers. In the preferred embodiment, the relative movement is accomplished by rotary motion and, more specifically, by rotary motion of the substrate containers.

A support platform **16** is supported from base **17** of the chamber by means of four symmetrically arranged support posts **18**. A bearing block **10** is attached to the top of platform **16** and rotatably supports a shaft **19**. A rotatable table **20** is securely attached to a flange **21** on the top of shaft **19** so that table **20** can be rotated about the axis of shaft **19**. The substrate containers **14** and **15** are secured on the top of table **20** as by means of bolts **22**.

In order to provide means for rotating table **20**, a drive shaft **25** is sealed in a rotary feed-through **26** connected vacuum-tight to the cover plate **5**. The outer end of shaft **25** is adapted to be driven from outside the chamber **2**. The drive can either be an automatic motor arrangement or a hand knob as shown at **27**. The lower end of shaft **25** has a sliding fit in a drive boss **28** which is securely attached to the top of plate **20** concentric with shaft **19**. Shaft **25** carries a key **29** which fits in a keyway in boss **28**. Thus, when the cover **5** is removed it carries with it the target electrodes **8** and **9** and the shaft **25**. Particularly if the rotary motion is hand driven, it is desirable to provide fixed indexing positions for table **20**. This is accomplished by providing a post **32** mounted on platform **16** and carrying a clamp **33** to which is attached a spring arm **34** carrying a roller **35** which is received in two diametrically opposed grooves **36** in the perhiphery of table **20**. Knob **27** can be provided with visual marks so that the operator will know which substrate container is positioned to surround which target electrode.

The substrate containers **14** and **15** are open at the top and have vertical apertures **37** extending down from the top rims thereof with sufficient width and depth to permit rotation of table **20** without causing physical contact between the substrate containers **14** and **15** and the target electrodes **8** and **9**. The axes of the substrate containers and the target electrodes are all located at the same radial distance from the rotational axis of shaft **19**. Thus, as table **20** is rotated, the locus of the vertical axes of substrate containers **14** and **15** trace out a circle about the axis of shaft **19** as indicated by the broken line **38** in FIG. 2. At two particular rotary positions of table **20**, established by the roller **35** and recesses **36**, the axes of the target electrodes **8** and **9** will coincide with the axes of the substrate containers **14** and **15**. These are the positions at which sputtering is instituted, as will be hereinafter described in more detail. In the drawings, one such position is shown in which targets **8** and **9** are within containers **14** and **15**, respectively.

In operation, the substrate containers **14** and **15** are loaded with substrates such as indicated at **41** in substrate container **14** in FIG. 2. The substrates can be supported in the containers in any convenient manner depending upon the configuration of the substrate. For example, if the substrates are elongated bars extending along the length of container **14**, they can be supported by spring clips **42** which are secured along the sides of the container **14**. In order to load the containers with substrates, the cover **5** is first removed together with the target electrodes **8** and **9**. The containers **14** and **15** can be loaded in place or they can be removed by unscrewing bolts **22**.

After the substrates have been loaded in the containers and the cover plate **5** with the target electrodes **8** and **9** has been replaced, chamber **2** is pumped down to an appropriate pressure such as 1×10^{-6} torr and an inert gas such as argon, to form the discharge plasma, is introduced into the chamber to a pressure of, for example, 5×10^{-3} torr. If not already so placed, the table **20** is rotated by knob **27** so that the target electrodes **8** and **9** are received within the substrate containers **14** and **15**. As previously stated, knob **27** is indexed so that the operator always knows whether container **14** surrounds target electrode **8** or target electrode **9**, and similarly for container **15**. The terminals **11** are connected to a conventional power supply (not shown) for providing a negative potential on the target electrodes with respect to the potential on the substrate containers **14** and **15**. Normally it is desired to operate the substrate containers at ground potential and this is done through the metallic circuit formed by the base of chamber **2**, posts **18**, bearing block **10**, shaft **19** and table **20**. The containers **14** and **15** are also made of metal.

As is conventional, the target electrode terminals **11** are adapted to be connected to a power supply for providing either a direct current or radio-frequency potential on the target electrodes with respect to the potential on the substrate containers, the target electrodes being energized either simultaneously or alternatively as will be hereinafter described in more detail. As will be understood by those skilled in the art, the center portions of the target electrodes must be electrically conductive but, if the power supply delivers radio-frequency energy to the terminals **11**, the outer surfaces can be either conductive or nonconductive material to be sputtered onto the substrates. If a direct current power supply is used, the target electrodes must be metallic. For this reason a radio-frequency power supply is preferred. If it is desired to sputter coat the substrates **41** with first one material and then another, the outer surface of target electrode **8** must consist of one of the desired materials and the outer surface of target electrode **9** must consist of the other desired material.

Assuming that the apparatus has been prepared for sputtering as previously described and it is intended to deposit two different materials and, for example, target electrode **8** contains the material to be sputtered first, then with target electrode **8** in substrate container **14**, radio-frequency energy is supplied to target electrode **8** while target electrode **9** is not connected to the power supply. The radio-frequency voltage on target electrode **8** will create a plasma within the container **14**; a negative direct current self-bias will be established on target electrode **8** as previously described; and ions in the plasma will strike the target electrode causing material to be sputtered therefrom and deposited on the substrates **41** in container **14**. The shielding effect of container **14** and container **15** will prevent any sputtered material from being deposited on substrates located inside container **15**. After the desired thickness of material from target **8** has been deposited, the power supply is turned off and table **20** is rotated 180° so that substrate container **15** surrounds target electrode **8**. Then target electrode **8** is again energized to sputter the base coating on the sub-

strates in container 15. It would, of course, be possible to maintain the substrate containers stationary and rotate the target electrodes. However, this is not preferred because it is difficult to conduct the high current to the target electrodes through a moving contact.

In cases where extreme purity precautions are in order, target electrode 9 remains unenergized while target electrode 8 is sputtering the base coating onto substrates in container 15. In this manner, there is no chance for material sputtered from target electrode 9 to diffuse through the system so as to cause even minute contamination of the purity of material being sputtered from target electrode 8. After both containers 14 and 15 have been sputtered with the base material from target electrode 8, target electrode 8 is deenergized, and target electrode 9 is energized to sputter the second coating within first one container and then within the other as previously described for sputtering from target electrode 8. If extreme purity precautions are not required, it is, of course, possible to energize both of the target electrodes after container 14 has been exposed to the base coat from target electrode 8 and container 14 has been moved to surround target electrode 9. This will provide the final coating in container 14 while container 15 is receiving the initial coating. Then it will merely be necessary to move container 15 to target electrode 9, which would then be energized while target electrode 8 is disconnected, and in this manner give container 15 the second coating.

Obviously, additional target electrodes and additional substrate containers could be employed. For example, three of each can be employed, with each of the target electrodes composed of a different material, or four of each can be employed with two target electrodes of first-coat material and the other two target electrodes of second-coat material, Alternatively, a single substrate container could be employed with a plurality of target electrodes of different material.

Although the primary benefit of the apparatus is the ability to provide sequential coatings of different materials with extreme purity, the apparatus is also useful to coat a large number of substrates with a one-material coating during a single pump-down cycle. In other words, all of the target electrodes may be of the same material with the container-type configuration of the substrate containers providing a plurality of well-defined and efficient sub-chambers in which sputtering can take place within the main container 2. Also, a relatively inexpensive apparatus having only a single target electrode could service a plurality of substrate containers to provide an efficient one-material coating on a large number of substrates without having to open the chamber 2.

Although containers 14 and 15, as shown in FIGS. 1 and 2, are substantial improvements in terms of preventing contamination of one sputter coating by another, it is, of course, possible to make the containers even more closed as shown by way of example schematically in FIGS. 3A and 3B wherein a container 14' is made of two completely separate half-cylindrical sections 45 and 46 which can be operated to move apart in order to admit the target electrodes, as shown in FIG. 3A, and then to move together in order to completely enclose the electrode as shown in FIG. 3B. In addition, the upper end of the substrate container 14' can have a partial top 47 on each of the half-cylinders which is provided with an aperture 48 only large enough to prevent breakdown between the target electrode and the container. Alternatively, the insulating bushing 10 can extend down below the top of the container 14', in which case the top of the container can closely confine the bushing without the problem of breakdown.

Although the invention has been described in detail with respect to certain preferred embodiments thereof, it will be understood that variations and modifications can be effected within the spirit and scope of the invention as described above and as defined in the appended claims.

What is claimed is:

1. Sputter coating apparatus comprising an evacuable chamber, a plurality of target electrodes in said chamber, wall means forming a hollow substrate container in said chamber, means for causing relative movement between said target electrodes and said substrate container to selectively place said target electrodes one at a time within and to remove same from said substrate container, means for supporting at least one substrate on the inside of said substrate container in a position spaced from said target electrodes when said electrodes are selectively positioned within said substrate container in order to permit sputter coating a substrate in said container when one of said target electrodes is within said substrate container, said substrate container having an apertured portion through which said target electrodes can be placed within and be removed from said substrate container, and said apertured portion providing a communication between said substrate container and said evacuable chamber whereby said target electrodes can be placed within and removed from said substrate container without removing said target electrodes from said evacuable chamber.

2. The sputter coating apparatus of claim 1 wherein said target electrodes are elongate in a given direction, said substrate container has a substantially cylindrical shape with the axis thereof being substantially parallel to the elongate axes of said target electrodes, and said target electrodes and substrate container being arranged such that when said target electrodes are selectively positioned in said substrate container they are positioned substantially coaxial with said substrate container.

3. The sputter coating apparatus of claim 2 wherein said apertured portion of said substrate container comprises two spaced-apart portions forming two elongate side openings extending parallel to the elongate axes of said target electrodes and an end opening communicating between said side openings, and wherein said moving means causes said target electrodes to be placed within said substrate container through one of said side openings and to be removed from said substrate container through the other of said side openings.

4. The sputter coating apparatus of claim 1 further comprising another substrate container in said chamber, said other substrate container having an apertured portion through which said target electrodes can be placed within and be removed from said other container, and said substrate containers being disposed so that when one of said target electrodes is within one of said substrate containers the other of said target electrodes is within the other of said substrate containers.

5. The sputter coating apparatus of claim 4 wherein said substrate containers are disposed spaced-apart from each other concentrically with respect to a common axis, said target electrodes are disposed spaced-apart from each other concentrically with respect to said axis, and said means for causing relative movement causes circular movement around said axis.

6. The sputter coating apparatus of claim 1 wherein said moving means comprises means for moving said substrate container while said target electrodes remain stationary.

7. The sputter coating apparatus of claim 4 wherein said wall means of said substrate containers prevent line-of-sight sputtering from the target electrode in one of said substrate containers into the interior of the other of said substrate containers.

8. The sputter coating apparatus of claim 5 wherein said moving means comprises means for moving said substrate containers while said target electrodes remain stationary.

9. The sputter coating apparatus of claim 1 wherein said substrate container comprises a plurality of com-

ponents which are movable relative to each other to accommodate the placement within and the removal from said substrate container of said target electrodes.

10. The sputter coating apparatus of claim **9** wherein said plurality of components of said substrate container comprises two half-cylindrical components, said components being movable apart from each other to accommodate the placement within and the removal from said substrate container of said target electrodes.

11. The sputter coating apparatus of claim **9** further comprising another substrate container in said chamber, said other substrate container being disposed so that when said one target electrode is within a substrate container another of said target electrodes is within said other substrate container.

12. The sputter coating apparatus of claim **1** further comprising means for applying a radio-frequency voltage to said target electrodes when selectively positioned in said substrate container, and said moving means comprises means for moving said substrate container while said target electrodes remain stationary.

13. Sputter coating apparatus comprising an evacuable chamber, a target electrode in said chamber, wall means forming a plurality of hollow substrate containers in said chamber, means for causing relative movement between said target electrode and said substrate containers to selectively place said target electrode within and to remove same from each of said substrate containers, means for supporting at least one substrate on the inside of each of said substrate containers in a position spaced from said target electrode when the target electrode is positioned within the respective substrate container in order to permit sputter coating a substrate in the respective container when said target electrode is within the respective substrate container, each of said substrate containers having an apertured portion through which said target electrode can be placed within and be removed from said substrate container, and said apertured portions providing a communication between their respective substrate containers and said evacuable chamber whereby said target electrode can be placed within and removed from said substrate containers without removing said target electrode from said evacuable chamber.

14. Sputter coating apparatus comprising an evacuable chamber, a plurality of target electrodes, wall means forming a plurality of hollow substrate containers, means for causing relative movement between said substrate containers and said target electrodes to selectively place either of said target electrodes within either of said substrate containers and to remove the received target electrode from the receiving substrate container, means for supporting at least one substrate on the inside of each of said substrate containers in a position spaced from said target electrodes when the electrodes are positioned within the substrate containers in order to permit sputter coating a substrate in a respective one of said substrate containers when either target electrode is within the respective substrate container, each of said substrate containers having an apertured portion through which said target electrodes can be selectively placed within and be removed from said substrate containers, and said apertured portions providing a communication between their respective substrate containers and said evacuable chamber whereby said target electrodes can be placed within and removed from said substrate containers without removing said target electrodes from said evacuable chamber.

15. The sputter coating apparatus of claim **14** wherein said target electrodes and said substrate containers are disposed with respect to each other such that when one of said target electrodes is within one of said substrate containers another of said target electrodes is within another of said substrate containers, and wherein said wall means of said substrate containers prevent line-of-sight sputtering from the target electrode in one of said containers into the interior of the other of said containers.

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