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SPUTTERING APPARATUS

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Fig. 1.

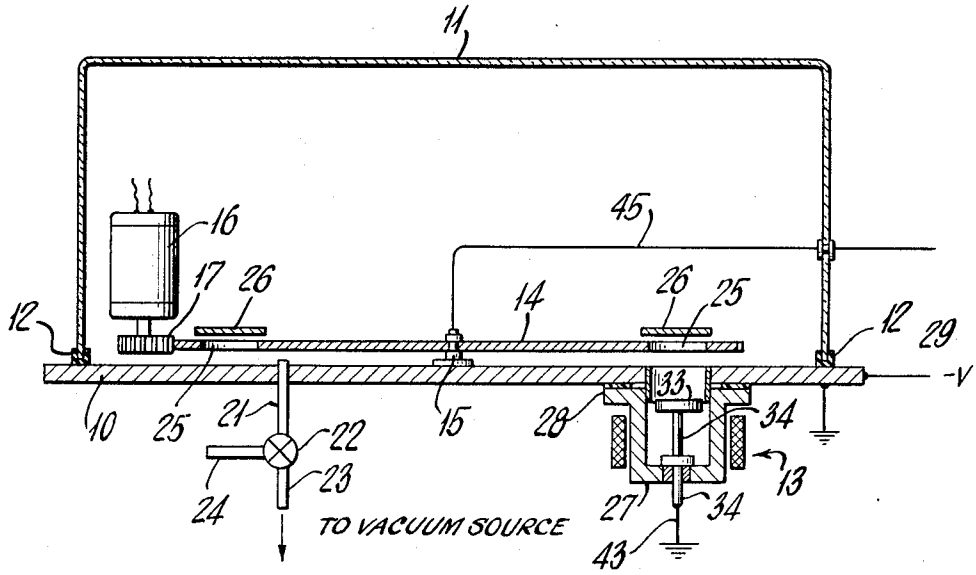
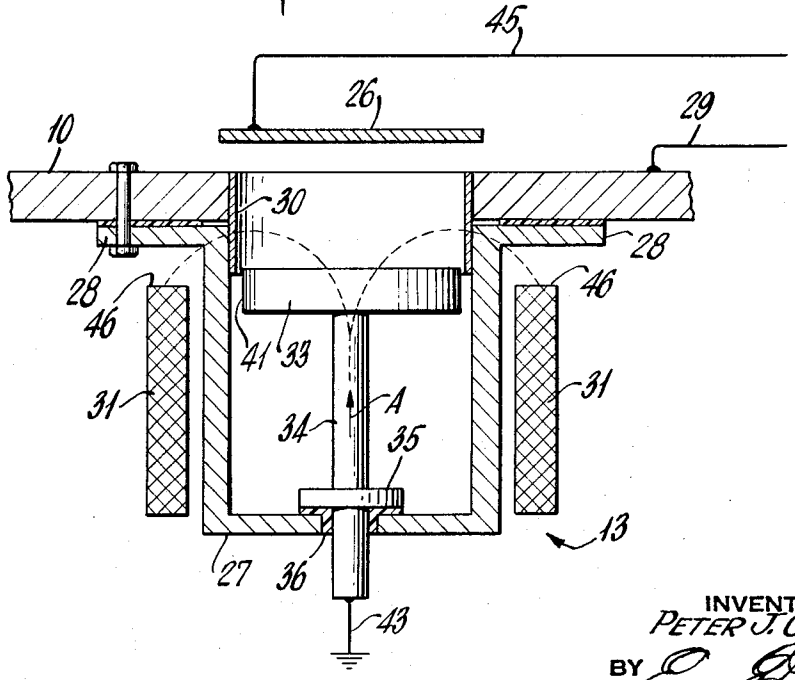


Fig. 2.



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SPUTTERING APPARATUS

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ABSTRACT OF THE DISCLOSURE

Sputtering apparatus for coating a work piece which includes an open-ended cathode shell having a material to be sputtered, magnetic means surrounding the shell for producing a magnetic field and an anode disposed within the cathode shell for producing an electric field to sputter the material to form the coating. The magnetic field includes a substantially linear central portion and nonlinear end portions. The cathode shell includes a layer of the material to be sputtered on the wall adjoining the open end of the cathode shell which intercepts at least a portion of the nonlinear magnetic field.

The present invention relates to sputtering apparatus and more particularly to sputtering apparatus of the type wherein the material is sputtered from a cathode onto a work piece under the influence of electric and magnetic fields of suitable amplitudes.

This invention constitutes an improvement of the sputtering apparatus disclosed in a copending U.S. patent application of applicant herein, Ser. No. 774,126, filed on Nov. 7, 1968, now U.S. Pat. No. 3,616,450 of October 1971, which includes an open-ended cathode and an anode shell partially surrounding an end of the cathode, and magnetic field producing means surrounding the anode shell. While the sputtering apparatus disclosed in applicant's copending application produces a thin film or coating of excellent uniformity and adherence, the area of a work piece which can be coated is somewhat limited. It is therefore one object of the present invention to provide improved sputtering apparatus generally and more particularly sputtering apparatus which utilizes the material to be sputtered more efficiently, has improved cooling efficiency and which can produce a thin film or coating on a work piece of greatly increased area without sacrificing the excellent uniformity, density, and high quality bond heretofore attained.

The aforementioned and other objects of the present invention are achieved according to the present invention by providing an open-ended cathode shell carrying the sputtering material, magnetic means surrounding the shell for producing a magnetic field within the shell having a substantially linear central portion and nonlinear end portions and an anode disposed within the cathode shell. The wall defining the open end of the cathode shell is provided with a layer of the material to be sputtered and this layer is positioned relative to the magnetic field producing means so that it intercepts at least a portion of the nonlinear portions of the magnetic field. A high negative potential relative to the anode potential is applied to the cathode shell to produce an electrical field for sputtering the material and form a thin film on a work piece.

It is a feature of the present invention to provide an anode electrode within the cathode shell.

It is another feature of the present invention to provide an anode electrode having a relatively flat electrode positioned transversely to the linear portion of the magnetic field.

The aforementioned and other objects and features of the present invention will become more apparent from

the following detailed description of the present invention taken in conjunction with a preferred embodiment as shown in the accompanying drawings.

In the drawings:

FIG. 1 is a cross-sectional view of one embodiment of the apparatus in accordance with the present invention which includes a glow discharge device; and

FIG. 2 is an enlarged cross-sectional view of the glow discharge device illustrated in FIG. 1.

Referring now to FIG. 1, the sputtering apparatus in accordance with the invention includes a base plate **10** disposed in a substantially horizontal position and having a bell jar **11** removably sealed to the top surface of the plate **10** by suitable sealing means **12**. The sputtering apparatus is generally denoted by the numeral **13**, and as will be described, is secured in sealed relationship to the base plate **10** by suitable means and opens into the interior of the bell jar **11**. A circular work supporting plate **14** is disposed within the bell jar and is pivotally mounted at **15** to the upper surface of the plate **10**. The plate **14** can be rotated by any suitable means as for instance a motor **16** carrying a drive wheel **17** of resilient material which contacts the periphery of the plate **14**.

A conduit **21** extends through the base plate and is connected on its outer end to a two-way valve **22**. A second conduit **23** connects the valve to a vacuum source for exhausting air from within the bell jar **11** and the sputtering device **13**. A third conduit **24** has one end connected to the valve and the other end connected to a source of inert gas such as argon or the like so that the gas pressure can be adjusted to the desired magnitude. Reactive gases such as oxygen and nitrogen can also be used when metal and dielectric films such as tantalum nitride or aluminum oxide are to be formed. To remove the bell jar **11** when the plating process has been completed, air can be admitted by disconnecting the vacuum source and opening conduit **23** to the atmosphere.

The circular plate **14** includes a plurality of openings **25** spaced uniformly from the center of the plate and the work pieces **26** or substrates on which thin films are to be deposited overlie these openings. During the operation one of the pieces **26** is aligned with the sputtering device **13** and is maintained in that position until the desired thickness of film is deposited on the underside thereof. Then without interrupting the operation of the sputtering device **13**, the plate **14** is rotated to bring the next successive work piece into alignment with the sputtering device, and it remains in that position until the desired film is deposited thereon. The operation is then continued in this manner until all of the work pieces have been coated. If desired, the plate **14** can be continuously rotated so that each work piece or substrate will receive some sputtered material during each revolution. Operation of the sputtering device **13** is then terminated and air is admitted into the bell jar **11** by the valve **22** which permits the bell jar to be raised for removal of the coated work pieces **26** and placement of the next set of work pieces to be coated. The glow discharge for operating the sputtering device **13** is obtained by applying substantially zero voltage to the anode **33** through a conductive member **34** and a high negative voltage to the cathode shell **27** through a conductor lead **29** to the base plate **10** as will be described. A fourth lead may be connected with the work support plate **14** to apply an additional bias voltage to the plate and thus to the work pieces when the latter are of a conductive material.

The sputtering device **13** is shown in detail in FIG. 2 and corresponding elements of FIGS. 1 and 2 have been denoted by like numerals.

In accordance with the present invention the cathode **27** is a single open-ended cylindrical shell with an out-

wardly projecting flange 28 at the open end thereof. The cathode shell 27 may be bolted or otherwise secured to the underside of the base plate 10 and is preferably hermetically sealed. While in the instant embodiment the flange 28 is shown to be attached to the underside of the base plate 10, it is apparent that other attaching procedures may be employed.

Since the cathode 27 is in contact with the base plate, a high negative voltage can be applied to the cathode by applying it directly thereto or through the base plate 10 by means of the conductor 29 as shown. The wall defining the opening in the open end of the cathode may be provided with a ring 30 of material to be sputtered. Of course, the cathode itself may be made of material that can be sputtered for coating the work piece 26 thereby obviating the need for separate rings of sputter material.

An annular magnet 31 preferably of permanently magnetized material surrounds the cathode shell 27. The magnet 31 is positioned relative to the cathode shell so that the upper end of the cathode shell 27 where the rim 30 of the sputtering material is positioned intercepts at least some portion of the nonlinear magnetic field.

The anode 33 is shaped in the form of a flat plate and positioned within the cathode shell 27. It is oriented so that its major surface is transverse to the linear portion A of the magnetic field and the axis of the cathode shell. The anode surface is disposed near the open end of the cathode shell to optimize the electric field created between the anode and cathode shell and enhance the sputtering efficiency. The anode 33 has a conductive stem 34 of a suitable shape which supports and connects the anode to a ground potential through the bottom of the cathode. The conductive stem 34 may include a flange 35 which is positioned to rest on the bottom of the cathode to provide better support for the anode. The stem 34 is also insulated from the cathode shell 27 by suitable means 36 so that a proper potential differential can be maintained therebetween. In addition, where necessary, a suitable sealant may be provided between the conductive stem number 34 and the cathode shell 27 to provide a hermetic seal.

It is desirable to have the configuration of the anode rim 41 conform with the configuration of the cathode 27 and have the spacing between the anode rim 41 and the cathode as small as possible in order to prevent a glow discharge from occurring therebetween. Furthermore, the cathode 27, though illustrated as being of cylindrical configuration, may of course take other suitable forms. It is however desirable that the cathode have a substantially uniform cross-sectional configuration in the vicinity of its open end where the sputtering material is located in order to produce a more uniform film and such configuration may be modified depending on the particular film requirements.

With the invention as described above, the anode 33 is connected to ground or substantially zero potential by the lead 43 while a voltage of the order of 1,000 volts negative is applied to the cathode lead 29. Under these conditions the glow discharge can be produced with an internal pressure of the order of 2×10^{-3} torr. The magnet 31 produces a magnetic field in the direction of the arrow A at a point centrally of the magnet. Under these conditions atoms of one or more materials to be sputtered from the cathode will be liberated from the cathode and move upwardly striking the underside of the work piece 26 and form a film thereon. In actual practice it has been found that when the cathode 27 is about 2.8 inches in diameter, it is preferable to maintain a distance between the underside of the work piece 26 and the ring 30 of the sputtering material of about two inches. If this distance is exceeded, it has been found that the coating rate is reduced though a uniform film will be deposited.

In the operation of the device in accordance with the invention, the substrate or work piece whether of a conductive or nonconductive material attains almost immediately a bias voltage of about 50 volts negative when

floating electrically. This self-biasing feature is most advantageous since the surface of the work piece is automatically "scrubbed" by ions attracted by the surface, and this increases the adherence of the film to the work piece. Ion scrubbing effects removal of many contaminants such as water vapor and hydrocarbons which not only interfere with adhesion but also contaminate the film. In prior known devices self-biasing voltages of the order of 6 to 8 volts are generally attained but such voltages are below the threshhold for ion-bombardment cleaning and thus have no effect. Moreover, the use of probes for biasing is not helpful since a conductive base film of at least 50 angstroms in thickness is required for affixing the probe and there is no effect on either the base film or its adhesion to the work piece. If desired, a bias can be applied to conductive work pieces 26 by means of lead 45 which of course would fix the bias at any desired value. It is of course evident that the anode and the cathode of the sputtering device are formed of nonmagnetic materials so that the desired magnetic field produced by the magnet 31 within the cathode shell is not disturbed.

The form of the invention described in connection with FIG. 2 is particularly useful when a DC voltage applied between the anode and the cathode. In this way a high intensity glow discharge is obtained with a high degree of stability notwithstanding the relatively low gas pressure within the device. It is believed that the high intensity glow discharge results from the fact that the specific relationship of the magnetic field to the cathode deflects electrons from the paths which they would normally follow in the absence of such a field with the result that the lengths of such paths are increased. This action increases the number of ionizing collisions between the electrons and the gas molecules and such collisions are necessary in order to obtain a high deposition rate of atoms from the sputtering material layer 30 of the cathode 27 onto the work piece 26.

It is found also that by positioning the anode within the cathode shell in the manner shown, the atoms of the sputtering material will cover a much larger area of the work piece and a uniform film can be deposited at a much higher rate than otherwise possible if the relative positions of the cathode and anode shells are reversed, i.e., where the cathode shell is disposed within the anode shell as shown in the copending application.

With the invention described above, operation can be effected with exceedingly low gas pressures as low as 2×10^{-3} torr, which results not only in purer films but also in increased adherence of the film to the substrate or work piece. Furthermore, since the work piece need not be secured to the cathode or anode, the sputtering apparatus is particularly adaptable for use in continuous production processes as there are well-known means for moving the substrates into position for plating and removing finished work pieces without interruption of operation.

While only certain embodiments of the invention have been illustrated and described, it is apparent that alterations, modifications and changes may be made without departing from the true scope and spirit thereof as defined by the appended claims.

What is claimed is:

1. Sputtering apparatus for coating a workpiece comprising a hollow cathode having an opening on one end and means hermetically sealing the other end, said cathode being adapted to support material to be sputtered, means at said one end of said cathode for supporting work to be coated and intercepting particles of said material emerging from said cathode, means hermetically enclosing said one open end and said work supporting means to permit evacuation of said hollow cathode, an anode within said cathode, magnetic means for producing a magnetic field within said cathode having a linear portion centrally aligned with said cathode and a non-linear portion intercepted by at least a portion of said cathode carrying the

material to be sputtered and means including said anode and cathode for producing an electric field within said cathode.

2. Sputtering apparatus according to claim 1 wherein said magnetic means at least partially surrounds said cathode.

3. Sputtering apparatus according to claim 1 wherein said anode comprises a disc disposed in substantially parallel relationship to said cathode opening.

References Cited

UNITED STATES PATENTS

3,616,450	10/1971	Clark	204—298
3,516,919	6/1970	Gaydou et al.	204—298
3,530,057	9/1970	Muly	204—298

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