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R. L. HALLEN ET AL
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SUPPRESSING TEMPERATURE RISE ADJACENT THE ANODE
USING A LOCALIZED MAGNETIC FIELD
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FIG. 1

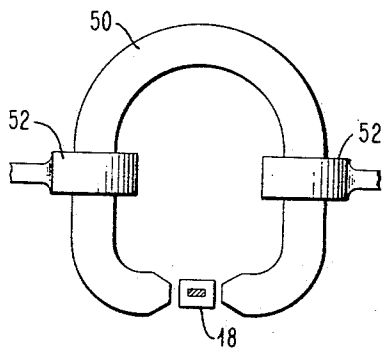
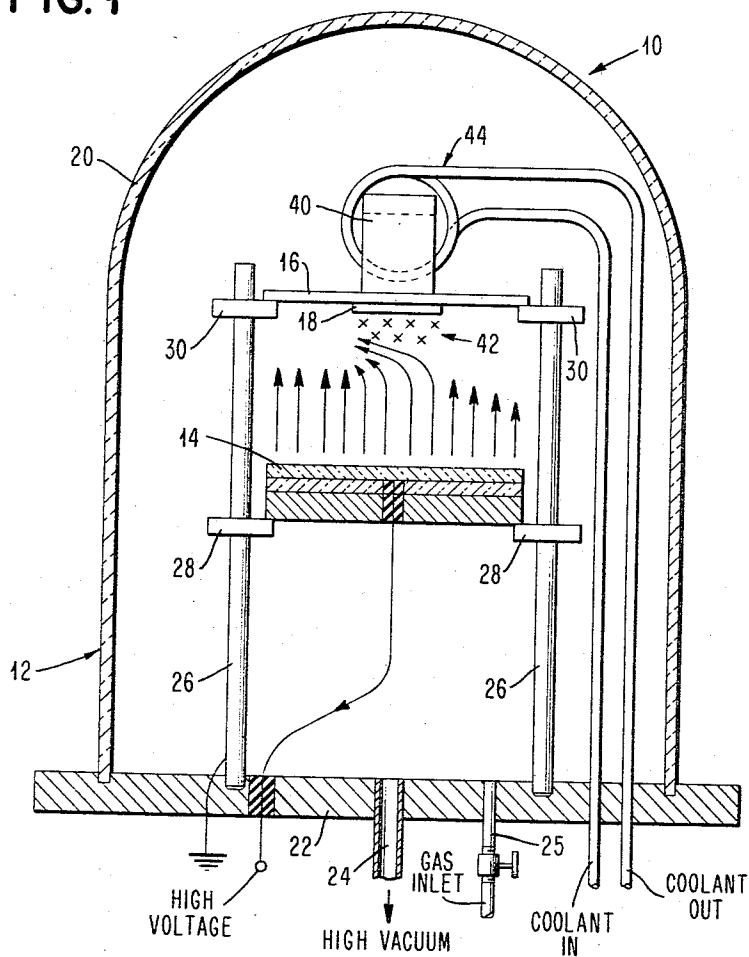


FIG. 2

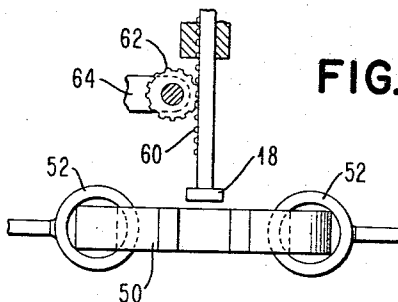


FIG. 3

INVENTORS
ROBERT L. HALLEN
ROBERT M. VALLETTA

BY *George D. Saile*
ATTORNEY

1

2

3,330,752

METHOD AND APPARATUS FOR CATHODE SPUTTERING INCLUDING SUPPRESSING TEMPERATURE RISE ADJACENT THE ANODE USING A LOCALIZED MAGNETIC FIELD

Robert L. Hallen, Colonie, and Robert M. Valletta, East Fishkill, N.Y., assignors to International Business Machines Corporation, Armonk, N.Y., a corporation of New York

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The present invention relates to the deposition of films of material upon articles, and more particularly to an improved apparatus for depositing films by cathode sputtering wherein the coating as deposited is maintained at a relatively low temperature by a magnetic deflection apparatus.

One of the problems in cathodic sputtering is the rapid rise in the temperature of the article as it is coated. The article being coated by cathodic sputtering is conventionally cooled by the use of a cooling jacket having cooling fluid running therethrough. The cooling jacket does help to prevent a rapid rise in the temperature of the article being coated, however, it does not cure the problem and the article over a short period of time will rise to undesirable high temperatures. This relatively uncontrolled temperature rise of the article and the film being deposited results in a deposited film having a variation in chemical and physical properties through its thickness. Further, high temperatures promote unwanted chemical reactions of the material being sputtered with the small residual amounts of oxygen, water vapor and other gases in the sputtering chamber.

It is thus an object of the present invention to provide an apparatus for maintaining the article being coated by the cathodic sputtering technique at a constant and relatively low temperature.

It is another object of this invention to provide a cathode sputtering apparatus for coating articles wherein a magnetic deflection apparatus is used to maintain the temperature of the article being coated at a constant and relatively low value.

It is another object of this invention to provide a cathodic sputtering apparatus for coating articles wherein the temperature of the article may be adjusted during the coating operation.

It is a still further object of the present invention to provide a cathode sputtering apparatus for coating articles wherein a magnetic deflection is used to maintain the article and coating being deposited relatively cool during sputtering and which includes means to adjust the magnetic deflection during the coating operation to thereby vary the cooling effect of the magnetic field on the article.

These and other objects are accomplished in accordance with the broad aspects of the present invention by providing a novel cathode sputtering apparatus. The cathode sputtering chamber is capable of holding a high vacuum. The article to be coated is positioned between the cathode and anode of the chamber. Suitable means is provided for impressing a voltage across the cathode and anode which acts to establish an electric field between the cathode and anode, and to cathodic sputter particles from the cathode onto the article. A localized magnetic field directly over the surface of the article and at substantially right angles to the electric field between the cathode and anode is generated by a suitable magnetic device. It is this magnetic field that deflects the charged particles away from the surface of the article with the resulting maintenance of the temperature of the article and coating at a relatively low value.

It has been discovered that the major cause of article heating in a glow discharge is the flow of electrons and negative ions to the article surface with the predominantly uncharged sputtered particles. The magnetic deflection structure causes the electrons and negative ions from the cathode to the anode to be deflected away from the article being coated and has no effect on the uncharged particles. The highly localized magnetic field deflects these charged particles from their relatively straight line path, away from the article surface, thereby greatly reducing their number which strikes the article. The result is the effective cooling of the article and the coating being deposited.

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

In the drawings:

FIGURE 1 is a partly sectional view of one form of the apparatus of the present invention;

FIGURE 2 is a top view of a horseshoe magnet deflection device; and

FIGURE 3 is a side view of the FIGURE 2 magnetic deflection device showing a suitable means for adjusting the positional relationship between the means for generating a magnetic field and the article to be coated.

Referring now, more particularly, to FIGURE 1, there is shown a cathode sputtering apparatus 10 which is composed basically of a chamber 12 capable of holding a high vacuum, a cathode 14 and an anode 16. The article or substrate 18 to be coated is illustrated as attached to the anode 16. The chamber 12 is constructed of two parts, a bell jar 20 and a plate 22. The vacuum chamber may be constructed of any of the usual materials, such as glass, porcelain, metal and the like.

The various inputs and outputs to the vacuum chamber are made through the plate 22. A chamber output port 24 is connected to a suitable vacuum pump (not shown) for removing gases from the chamber. The variable leak gas input tube 25 is connected to a source of gas, such as an inert gas, with which the chamber may be filled prior to the application of a voltage across the cathode and anode to cause cathodic sputtering.

Rods 26 fixed into the base plate 22 together with rests 28 and 30 mounted on the rods 26 support, respectively, the cathode 14 and anode 16 centrally within the vacuum chamber 12. The rests 28 and 30 are composed of a suitable material, such as stainless steel. The rods 26 are connected to electrical ground which is the anode electrical connection.

The anode of the chamber can be composed of any suitable conductive material, such as aluminum. The article or substrate 18 to be coated may be conveniently attached to the anode 16 by any conventional attaching means. Alternatively, the substrate 18 may be positioned in front of the cathode such as by securing the substrate 18 directly to the rods 26.

The cathode 14 is composed of the material to be sputtered onto the article 18. The high voltage connection is applied to the cathode. The connection must be electrically insulated from all other parts of the vacuum chamber 12. The cathode 14 is supported on any suitable structure, such as an aluminum plate resting on rests 28 and a quartz plate between the aluminum plate and the cathode 14 to insulate the cathode from the anode.

The means 40 for generating a localized magnetic field 42 directly over the surface of the article or substrate 18 and at substantially right angles to the electric field must be a closed flux path magnetic field, such as the horseshoe magnet illustrated in the drawings. The magnetic field 42 that is generated will then not effect the charged

particles moving from the cathode which are not directly over the substrate. Therefore, the result of this type of a magnetic field is to only materially effect the charged particles which would, without the use of the magnetic field, strike the article surface. Any other type of magnet structure, such as an opposed pair of bar magnets of normal length, cannot be used to produce the present invention's cooling effect because the fields produced by such magnets are not sufficiently localized. The bar magnet's field pulls toward the substrate as many charged particles as it deflects away from the substrate. However, bar magnets can be used to produce a localized field between their ends if they are extremely long and their ends are positioned close together.

A cooling means 44 is preferably used to cool the means 40 for generating a localized magnetic field. The cooling of means 44 may be in the form of a cooling coil surrounding the means 40 having cooling fluid therein. The cooling means 44 is used to maintain the means 40 at a temperature low enough that its magnetic field strength remains substantially constant during the coating period. The magnetic field is reduced with increased temperature so the magnet's cooling effect on the substrate 18 would also be reduced if the magnet itself were not cooled.

The horseshoe magnet, whether a permanent or electromagnet type, is the preferred means for generating a localized magnetic field 42 directly over the surface of the article. The flux path external to the magnet is solely localized between the magnet's poles. The remaining flux path is within the body of the magnet. This is inherent in the horseshoe magnet structure. The external field of the horseshoe magnet, therefore, can be concentrated in the required manner, directly over the substrate, to produce the desired cooling effect.

FIGURES 2 and 3 illustrate a means for adjusting the positional relationship between the means 40 for generating a magnetic field and the substrate 18 to be coated. This adjusting technique is effective to vary the cooling effect of the magnetic field on the substrate. A horseshoe magnet 50 which can either be a permanent magnet or an electromagnet is shown in the FIGURE 2 suspended by holding means 52. The substrate 18 to be coated is positioned between the horseshoe magnet 50 pole pieces. The pole pieces are shown to be tapered. The tapered pole piece structure is a preferred means for increasing the intensity of the flux path external to the magnet. In this manner, a high intensity magnetic field can be adjustably located solely over the surface of the article 18.

FIGURE 3 illustrates a means for adjusting the positional relationship between the horseshoe magnet 50 and the article 18 to thereby vary the cooling effect of the magnetic field on the article. While it is obvious that either the horseshoe magnet 50 or the article 18 may be moved relative to the other one, it is preferred to hold the horseshoe magnet 50 stationary and move the article 18. One suitable means for adjustably moving the article between the pole pieces of the magnet 50 is the means illustrated in FIGURE 3. This means includes a rack 60 and a pinion 62. The rack is moved by the rotation of the pinion 62. The article 18 is fixed to the end of rack 60. Means 64 are provided for turning the pinion 62 to adjust the position of the article 54 in relation to the pole pieces of the magnet 50 to vary the cooling effect of said magnetic field on the article 18 and the coating being deposited.

A wide range of materials, such as all metals, alloys, non-metals and metaloids, can be sputtered cathodically as is well known in the art. Even the ferromagnetic metals, that is iron, cobalt and nickel, can be sputtered without being effected by the disclosed means 40 for generating a magnetic field concentrated over the surface of the article to be coated. This is because the sputtered

particles are so small that the particles of these metals are paramagnetic dipoles and not ferromagnetic. The magnetic field, therefore, has little effect on the uncharged sputtered particles of these normally ferromagnetic metals. It is only when several of these sputtered ferromagnetic metal particles are brought together that the sum of the particles is ferromagnetic.

Further, as is well known in the art, the cathodic sputtering chamber can be filled with gases through the gas inlet 25 which react chemically with the metal or non-metal being cathode sputtered. By this reaction a compound, such as silicon dioxide, can be deposited on the article surface 18. In this relation the apparatus of the present invention is particularly valuable, since by use of the temperature adjusting means a first nonreacted layer may be deposited, followed by depositing a reactive layer in the same chamber simply by changing the temperature of the surface of the article being coated. This surface change increase in temperature could be enough to promote the chemical reaction of the sputtered material with gases in the chamber at the higher temperature but not at the lower temperature.

The following examples are included merely to aid in the understanding of the invention and variations may be made by one skilled in the art without departing from the spirit of the invention.

Example 1

The sputtering chamber 10 of FIGURE 1 was used with the exceptions that the means 40 for generating a magnetic field was not used and a cooling jacket was placed on the anode 16. Water was circulated through the cooling jacket, to help cool the anode and the article to be coated. The anode was an aluminum plate. The cathode used was a four-inch diameter silicon wafer. The effective cathode area was 77 square centimeters. The article coated was a one inch diameter silicon wafer. The spacing between the cathode and the article was three-quarters of an inch. The chamber was evacuated to approximately 3×10^{-6} mm. of mercury. Pure oxygen was passed into the chamber until the chamber pressure was 125 microns. The sputtering voltage used was 1800 volts D.C. and the current was 350 milliamps. Within a period of less than one minute after the sputtering voltage was applied between the cathode and the anode, the substrate became a bright red color. It was estimated that the temperature was greater than 800° C. Sputtering was discontinued.

Example 2

The sputtering chamber 10 of FIGURE 1 was used, including the means 40, but with the exceptions that the magnet cooling means 44 was not used and a cooling jacket was placed on the anode 16. Water was circulated through the cooling jacket to help cool the anode and the article to be coated. The anode was an aluminum plate. The cathode used was a four-inch diameter silicon wafer. The effective cathode area was 77 square centimeters. The article coated was a one inch diameter wafer. The spacing between the cathode and the article was three-quarters of an inch. The chamber was evacuated to approximately 3×10^{-6} mm. of mercury. Pure oxygen was passed into the chambers until the pressure was 47 microns. A thermocouple was bonded to the substrate 18. A sputtering voltage of 2000 volts D.C. and a current of 400 milliamps were used. A permanent horseshoe magnet rated at 150 gauss was used. Cathodic sputtering was continued for nine minutes after application of the voltage between the cathode and the anode. The resulting silicon dioxide film was 4000 Angstroms in thickness. The coating was continuous and excellent in appearance. The article surface temperature was measured by the thermocouple and is given in the following table as against time in minutes.

5
TABLE

Wafer temperature in ° C.:	Time in minutes
≈15 -----	0
200 -----	2
310 -----	3 5
360 -----	7½
400 -----	9

It may be observed from comparing the results of the two examples of reactive sputtering that the use of the magnetic cooling technique of the present invention showed a marked improvement over not using the magnetic cooling technique. In Example 1, wherein no magnetic cooling was used, the article surface became so very hot after a matter of seconds that sputtering had to be discontinued. Compare, however, in the Example 2, wherein the magnetic cooling technique was used, the reactive sputtering was continued for nine minutes and the wafer temperature reached only 400° C. in that relatively long period of time. Also, in Example 2, a substantially higher power was used than in the Example 1. This increased power would be expected to increase the temperature of the wafer substantially.

The invention thus provides an improved apparatus for cathodic sputtering. The addition of the magnetic field generating structure greatly improves the temperature control of the article during the sputtering operation so that increased voltages and increased sputtering times can be used. The magnetic field has no adverse effect on the uncharged particles being sputtered, even when ferromagnetic metals are being sputtered. Further, means are provided to adjust the temperature of the article and the coating being deposited during the sputtering operation to allow further flexibility to what has been a somewhat difficult coating technique.

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

What is claimed is:

1. Apparatus for coating an article comprising: a chamber capable of holding a high vacuum; means for evacuating said chamber; means for providing gas to said chamber; a cathode and an anode within said chamber; means for positioning said article between said cathode and anode and adjacent to said anode; means for impressing a voltage across said cathode and anode which acts to establish an electric field between said cathode and anode, and to cathodic sputter particles from the cathode; means for generating a localized magnetic field directly over substantially the entire surface of said article and at substantially right angles to the said electric field whereby charged particles are deflected away from the surface of said article and the temperature of said article is maintained at a relatively low value; and means for adjusting the positional relationship between the said means for generating a magnetic field and said article to thereby vary the cooling effect of the magnetic field on the said article.
2. Apparatus for coating an article comprising: a chamber capable of holding a high vacuum; means for evacuating said chamber; means for providing gas to said chamber; a cathode and an anode within said chamber; means for positioning said article between said cathode and anode, and adjacent to said anode; means for impressing a voltage across said cathode and anode which acts to establish an electric field between said cathode and anode, and to cathodic sputter particles from the cathode;

6

a closed flux path means for generating a localized magnetic field directly over substantially the entire surface of said article and at substantially right angles to the said electric field whereby the temperature of said article is maintained at a relatively low value; and

means for adjustably moving the said article in said magnetic field to thereby vary the cooling effect of the magnetic field on said article.

3. The apparatus of claim 2 wherein said closed flux path means is a horseshoe permanent magnet.

4. The apparatus of claim 2 wherein said closed flux path means is a horseshoe electromagnet.

5. Apparatus for coating an article comprising: a chamber capable of holding a high vacuum; means for evacuating said chamber; means for providing gas to said chamber; a cathode and an anode within said chamber; means for positioning said article between said cathode and anode and adjacent to said anode; means for impressing a voltage across said cathode and anode which acts to establish an electric field between said cathode and anode, and to cathodic sputter particles from the cathode;

means for generating a localized magnetic field directly over substantially the entire surface of said article and at substantially right angles to the said electric field whereby charged particles are deflected away from the surface of said article and the temperature of said article being thereby maintained at a relatively low value;

means for adjusting the positional relationship between the said means for generating a magnetic field and said article to thereby vary the cooling effect of the magnetic field on the said article; and means for cooling the said means for generating the localized magnetic field.

6. Apparatus for coating an article comprising: a chamber capable of holding a high vacuum; means for evacuating said chamber; means for providing gas to said chamber; a cathode and an anode within said chamber; means for positioning said article between said cathode and anode and adjacent to said anode; means for impressing a voltage across said cathode and anode which acts to establish an electric field between said cathode and anode, and to cathodic sputter particles from the cathode;

a horseshoe magnet positioned so that the said article is in the magnet's external magnetic field between its pole pieces whereby the temperature of said article is maintained at a relatively low value; and means for adjustably moving the said article between the pole pieces of said magnet to vary the cooling effect of the said magnetic field on the said article.

7. Apparatus for coating an article comprising: a chamber capable of holding a high vacuum; means for evacuating said chamber; means for providing gas to said chamber; a cathode and an anode within said chamber; means for positioning said article between said cathode and anode and adjacent to said anode; means for impressing a voltage across said cathode and anode which acts to establish an electric field between said cathode and anode, and to cathodic sputter particles from the cathode;

a horseshoe magnet positioned so that the said article is in the magnet's external magnetic field between its pole pieces whereby charged particles are deflected away from the surface of said article and the temperature of said article being thereby maintained at a relatively low value;

means for adjustably moving the said article between the pole pieces of said magnet to vary the cooling

7

- effect of the said magnetic field on the said article;
and
means for cooling the said horseshoe magnet whereby
its magnetic field strength is maintained substantially
constant during the coating operation. 5
8. The apparatus of claim 7 wherein said horseshoe
magnet is a permanent magnet.
9. The apparatus of claim 7 wherein said horseshoe
magnet is an electromagnet.
10. The apparatus of claim 7 wherein said pole pieces 10
of the horseshoe magnet are shaped to produce a high
intensity external field between said pole pieces.
11. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
means for evacuating said chamber;
means for providing gas to said chamber;
a cathode and an anode within said chamber;
means for positioning said article between said cathode
and anode and adjacent to said anode;
means for impressing a voltage across said cathode 20
and anode which acts to establish an electric field
between said cathode and anode, and to cathodic
sputter particles from the cathode;
a horseshoe magnet positioned so that the said article 25
is in the magnet's external magnetic field between
its pole pieces whereby charged particles are de-
flected away from the surface of said article and the
temperature of said article being thereby maintained
at a relatively low value;
means for cooling the said horseshoe magnet whereby 30
its magnetic field strength is maintained substan-
tially constant during the coating operation.
a rack and pinion;
said rack being moved by the rotation of said pinion;
said article being mounted on the end of said rack;
means for turning said pinion to adjust the position 35
of the said article in relation to the said pole pieces
of said magnet to vary the cooling effect of the said
magnetic field on the said article.
12. Apparatus for coating an article comprising: 40
a chamber capable of holding a high vacuum;
means for evacuating said chamber;
means for providing gas to said chamber;
a cathode and an anode within said chamber;
means for positioning said article between said cathode 45
and anode and adjacent to said anode;
means for impressing a voltage across said cathode
and anode which acts to establish an electric field
between said cathode and anode, and to cathodic
sputter particles from the cathode;
a horseshoe magnet positioned so that the said article 50
is in the magnet's external magnetic field between
its pole pieces whereby charged particles are deflected

8

- away from the surface of said article and the tem-
perature of said article being thereby maintained at
a relatively low value;
a cooling coil surrounding said horseshoe magnet hav-
ing cooling fluid therein to maintain the said magnet
at a temperature low enough that its magnetic field
strength remains substantially constant during the
coating period;
a rack and pinion;
said rack being moved by the rotation of said pinion;
said article being mounted on the end of said rack;
means for turning said pinion to adjust the position
of the said article in relation to the said pole pieces
of said magnet to vary the cooling effect of the said
magnetic field on the said article.
13. The method of coating an article by sputtering,
wherein said article is arranged within a closed, evacu-
ated chamber containing a suitable pressure of ionizable
gas comprising:
providing a cathode and anode within said chamber
with said article positioned adjacent to said anode
and between said cathode and anode;
impressing a voltage across said cathode and anode
to establish an electric field between said cathode
and anode, and to sputter particles from the cath-
ode; and
generating a localized magnetic field directly over sub-
stantially the entire surface of said article and at
substantially right angles to the said electric field
whereby the temperature of said article is main-
tained at a relatively low value.
14. The method of coating an article of claim 13 and
further comprising:
adjusting the position of said localized magnetic field
in relation to said article during the coating method
to thereby vary the cooling effect of the magnetic
field on said article.

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