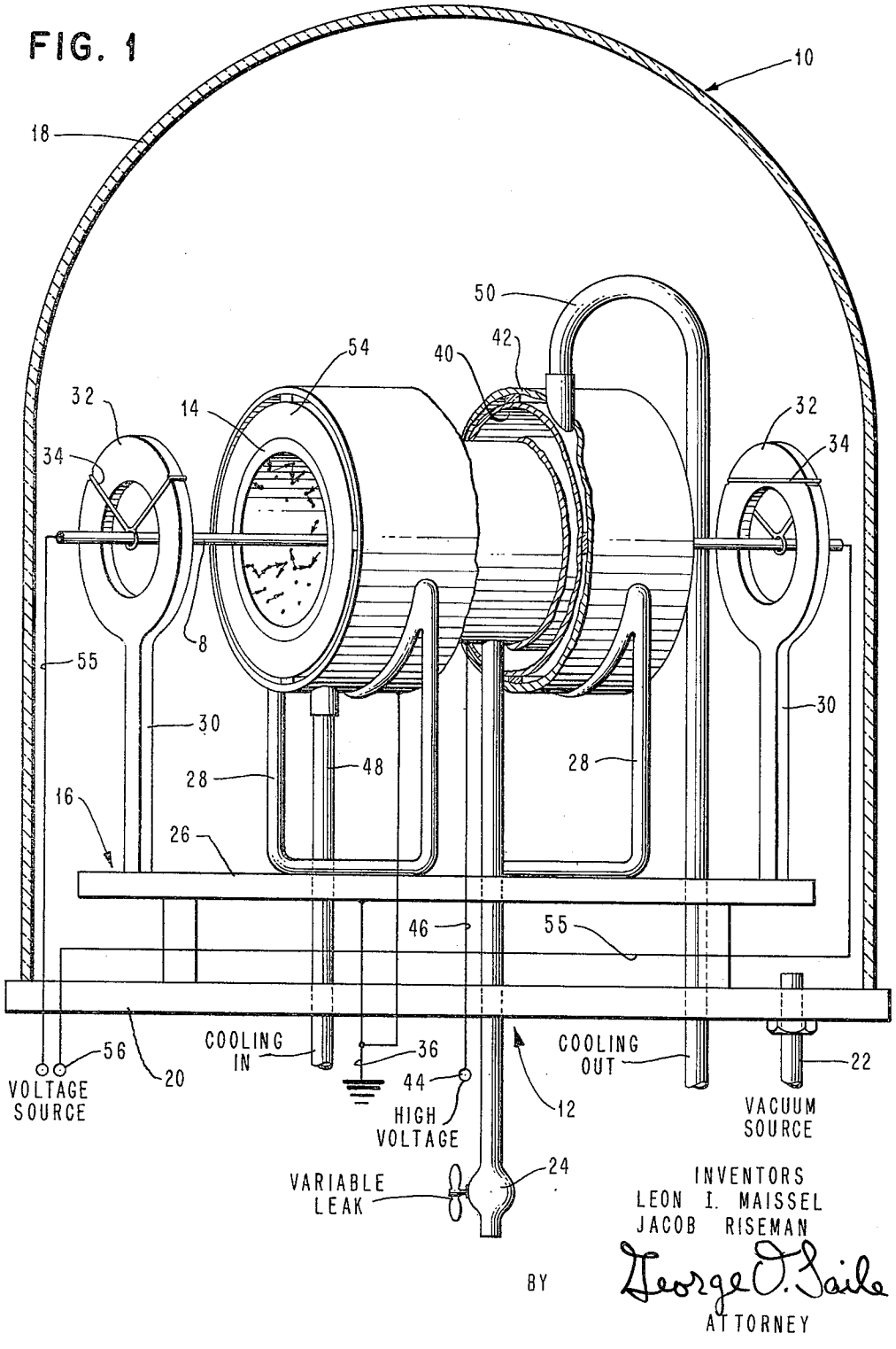
May 10, 1966 L. I. MAISSEL ET AL 3,250,694

APPARATUS FOR COATING ARTICLES BY CATHODE SPUTTERING

Filed Oct. 17, 1962 3 Sheets-Sheet 1

FIG. 1



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APPARATUS FOR COATING ARTICLES BY CATHODE SPUTTERING

Filed Oct. 17, 1962 3 Sheets-Sheet 2

FIG. 2

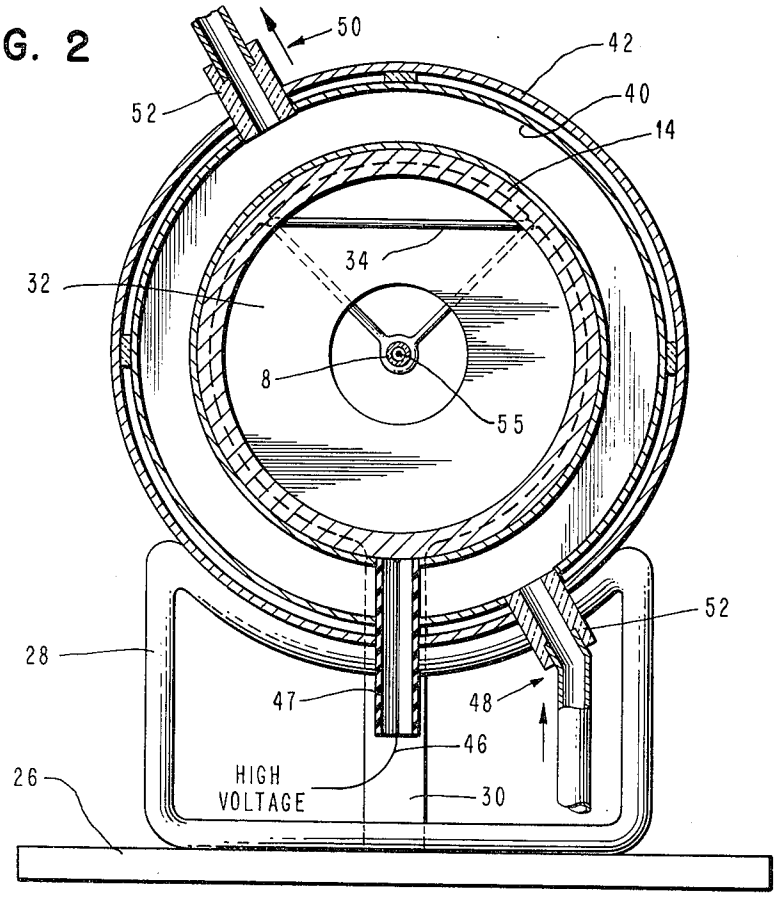


FIG. 3

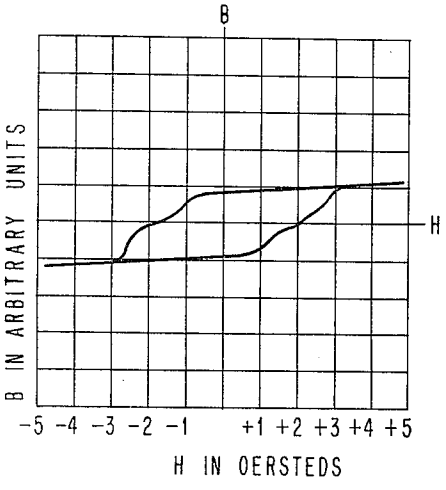
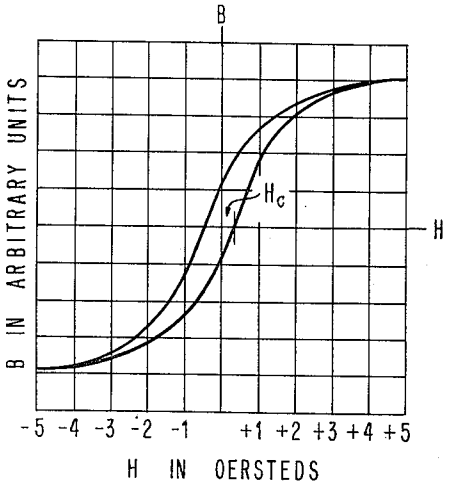


FIG. 4



May 10, 1966 L. I. MAISSEL ET AL 3,250,694

APPARATUS FOR COATING ARTICLES BY CATHODE SPUTTERING

Filed Oct. 17, 1962 3 Sheets-Sheet 3

FIG. 5

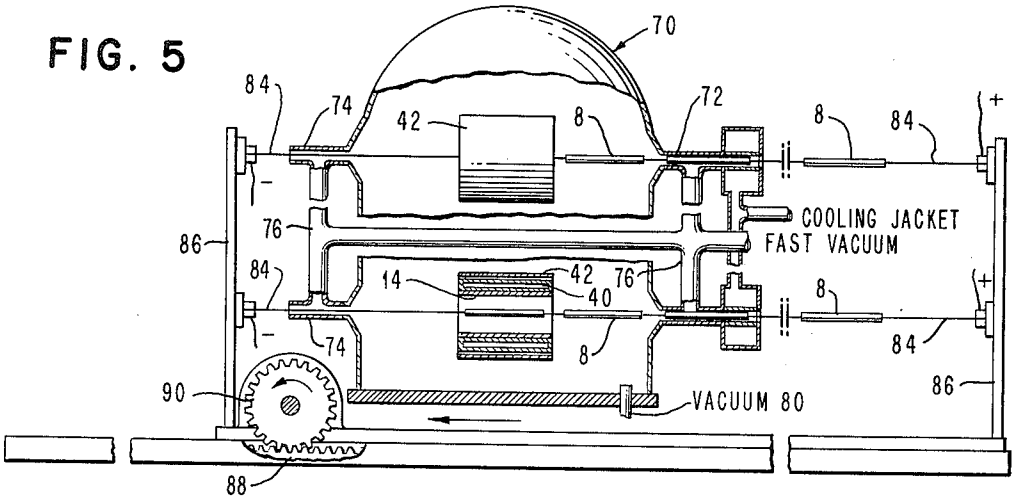
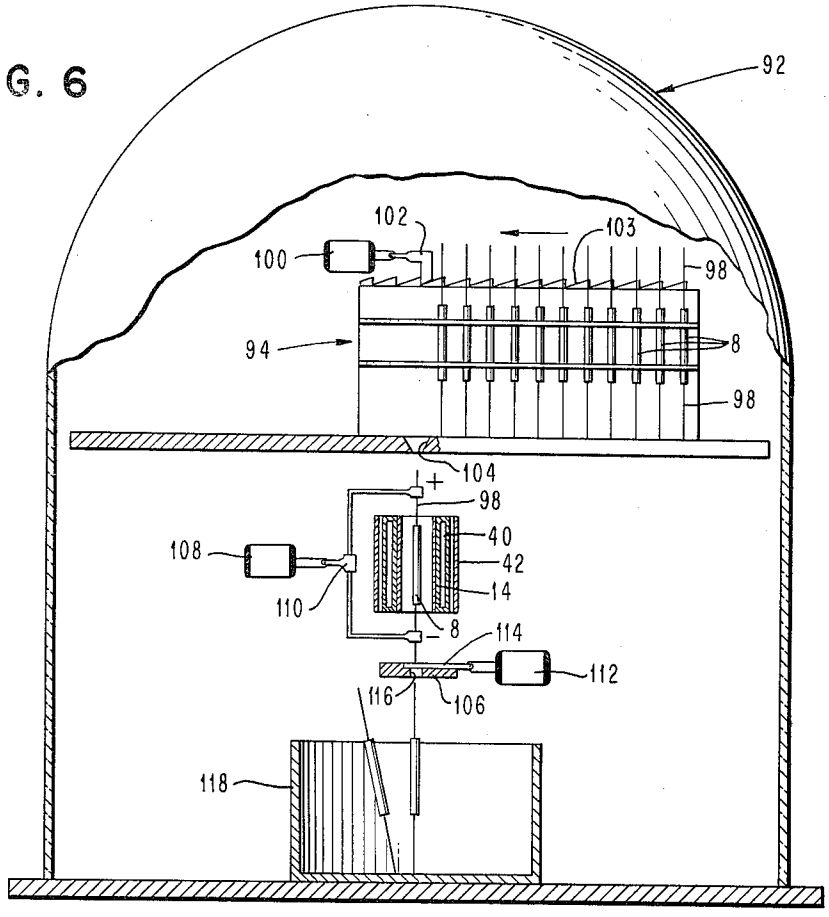


FIG. 6



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3,250,694

APPARATUS FOR COATING ARTICLES BY CATHODE SPUTTERING

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23 Claims. (Cl. 204—298)

The present invention relates to the deposition of thin films of materials upon articles, and more particularly, to an improved method and apparatus for depositing thin films by cathode sputtering.

The prior art methods for coating articles by means of cathode sputtering are uneconomical and unsuitable to mass production techniques. There has not been, until the present time, a satisfactory way to confine the materials sputtered from the cathode for deposit only upon the desired area of the article. A large portion of the material sputtered does not reach the article to be coated but is distributed throughout the vacuum chamber. The result is a loss of expensive cathodic material and a constant apparatus clean-up problem.

The prior art cathode sputtering procedures are basically batch type. An automatic or semi-automatic method has not been forthcoming primarily because of the frequent clean-up necessary. The frequent clean-up negatives the advantages that might be gained through automated procedures.

The problem of coating cylindrical or irregular articles by cathode sputtering has not been solved because of the inherent problems involved. To coat cylindrical articles using conventional cathode sources would require either the cathode source or the cylindrical article to be rotated. The mechanical rotating mechanism for this type of structure would be cumbersome and expensive. In addition, the resulting coatings would probably not be uniform over the external surface of the cylindrical article.

The fabrication of thin magnetic film devices for use as storage elements in a digital computer has been under considerable study by the computer industry. The cylindrical closed flux thin film magnetic core structure is one core geometry under consideration. These devices have been made by electroplating and vacuum evaporation procedures until the advent of the present invention.

The electroplating and vacuum evaporation procedures, however, have inherent disadvantages. In the electroplating method there is a need for a conductive underlayer. Since the basic substrate is composed of a siliceous material, preferably glass, cylinder it is necessary to apply a conductive underlayer, such as by vacuum evaporation, onto the siliceous cylinder. Further, the current density distribution associated with the resistance of the underlayer must be finite and in practice relatively sizable. The vacuum evaporation method has problems associated with it, although it would not suffer from the electroplating limitations and is a one step operation. The principal problem is the maintenance of a composition uniformity over the desired thickness range, due to the large amounts of material that must be evaporated. Where an alloy, for example, is evaporated the lowest vaporizable metal will first evaporate, then the next lower and so forth. This method then has obvious limitations in the deposition of alloys.

It is an object of the present invention to provide a method and apparatus for inexpensively and uniformly depositing a wide variety of coating materials onto articles of any shape.

It is another object of this invention to provide a cathode sputtering method and apparatus for coating articles irrespective of geometry at high sputtering rates.

It is another object of this invention to provide a cathode sputtering method and apparatus for confining the glow discharge within a cylindrical cathode whereby particles not deposited onto the article will return to the cathode surface and are again sputtered.

It is another object of this invention to provide a cathode sputtering method and apparatus which will allow the tailoring of the physical and chemical properties of the sputtered layer through the control of the substrate temperature.

Further, it is an object of this invention to provide a continuous cathode sputtering method and apparatus for producing a large number of coated articles rapidly and efficiently by the cathode sputtering technique.

It is a still further object of the present invention to provide a cathode sputtering method and apparatus suitable for fabricating closed flux thin magnetic films useful as storage elements in digital computers.

These and other objects are accomplished in accordance with the broad aspects of the present invention by providing a novel cathode sputtering method and apparatus. The cathode structure is in the form of a hollow cylinder. The article to be coated is located within the cathode cylinder. The cylindrical cathode is positioned within the cathode sputtering vacuum chamber and the pressure level of the chamber regulated so that the glow discharge fills and is confined to the inside of the cathode. During this glow discharge, there is effectively a gas of the cathode composition inside the cylindrical cathode. This cathode composition material will be uniformly deposited over the surface of any object within the cathode irrespective of the object's shape or position in the cylindrical cathode. Further, if there is sufficient room within the cathode more than one article could be coated at a time within a single cylindrical cathode.

The particles that are sputtered from the cathode will either strike the article and remain there as a portion of the coating or they will continue their movement until they strike the other side of the cathode. The loss of the cathodic composition from the cylindrical cathode is thus kept to a low value. The remaining portion of the vacuum chamber will remain clean for long periods of time and, more important, the loss of expensive materials will be virtually eliminated.

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 perspective, partially sectional view of one form of the apparatus of the present invention;

FIGURE 2 is a vertical sectional view illustrating the construction of the cylindrical cathode of the present invention;

FIGURE 3 is a B–H hysteresis loop taken in the easy direction of a thin closed-flux ferromagnetic film made according to the present invention;

FIGURE 4 is a B–H hysteresis loop taken in the hard direction of a closed-flux thin ferromagnetic film made according to the present invention;

FIGURE 5 is a first automatic sputtering apparatus useful in coating a large number of articles; and

FIGURE 6 is a second automatic apparatus for coating a large number of articles.

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 substantially cylindrical cathode **14** and an anode **16**. The article **8** to be coated is positioned within cathode **14**. The chamber **12** is constructed of two parts, a bell jar **18** and a plate **20**. The vacuum

chamber may be constructed of any of the usual materials such as glass, porcelain, metal or the like.

The various inputs and outputs to the vacuum chamber are made through the plate **20**. A chamber output port **22** is connected to a suitable vacuum pump (not shown) for removing gases from the chamber. The variable leak gas input tube **24** 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.

A base plate **26** is situated upon the plate **20** and insulated therefrom. The base plate **26** is constructed of a conductive metal. The cathode **14** is supported by a cradle means **28** which is secured to the base plate. The cradle means **28** is constructed of an insulating material, such as Pyrex glass. The cradle may be made by bending Pyrex glass tubes into the desired supporting configuration. Upright structures **30** project from the base plate **26** on either side and opposite to the open ends of the cathode. The upright structures **30** each have annular upright portion **32** which is directly opposite to an open side of the cylindrical cathode. Attachment means **34** composed of an insulating material such as glass are supported by each of the upright structures for holding the article **8** to be coated within the cylindrical cathode. The upright structures **30** are composed of an electrically conductive metal and made of the anode of the sputtering chamber by electrical connection **36** to the base plate.

Referring now to FIGURE 2, in addition to FIGURE 1, surrounding the substantially cylindrical cathode **14** there is a cooling jacket means **40** and a cylindrical grounded conductive shield **42** in that order. The cathode **14** is connected to a high voltage source **44** through electrical conductor **46**. The high voltage conductor is insulated from the coolant within the cooling jacket means **40** by an insulating tube **47**. The coolant input and output means **48** and **50** are connected to the cooling jacket means through the plate **20** from a coolant source (not shown). In each coolant line, there is a ceramic insulator tube **52** which electrically insulates the coolant source from the high voltage of the cathode.

The cooling jacket means is preferably contiguous with the external surface of the cylindrical cathode. Where practical, the cooling jacket surface contiguous to and the ends **54** substantially perpendicular to the cathode should be composed of essentially the same material as the cathode. These precautions as to material are taken to reduce all possible sources of contamination from the applied sputtered coating.

The variable leak gas input tube **24** is connected through the shield **42**, cooling jacket **40** and cathode **14** so that the input gas flows directly into the center of the cylindrical cathode **14**. The gas is thereby used to cool the article **8** during the cathode sputtering period. The article temperature is thereby brought under some control.

In the fabrication of thin ferromagnetic bistable films it is necessary to magnetically orient the film as deposited upon the cylindrical substrate in a substantially circumferential direction. One convenient technique for orienting is shown in FIGURE 1. A conductor **55** is threaded through the cylindrical article. The conductor **55** is connected to either an A.C. or D.C. voltage source **56**.

In the operation of the invention it has been found that the glow discharge may be confined to the inside of the cylindrical cathode, rather than being present over the entire surface of the cathode as would be expected. Experiments show that there are three forms which a glow discharge can assume where the cathode is cylindrical. At high pressures within the vacuum chamber, the glow is concentrated on the outer edges of the cylinder. At low pressures, the discharge takes the form of a very thin filament along the axis of the cathode. It is only at intermediate pressures that the glow fills and is confined to the inside of the cathode.

The intermediate pressure range in which the glow discharge fills the cylindrical cathode is a function of the internal diameter of the cathode. The mean free path of the gas at that pressure in millimeters of mercury is of the order of the internal diameter of the cylinder. For example, a hollow cathode of 1 cm., would operate as described at about 1 mm. of mercury pressure. Larger diameter cathodes will operate at lower pressure. Were the inside diameter increased to 10 cm., the pressure of the chamber must be reduced by a factor of 10 to approximately 0.1 mm. of mercury to cause the glow discharge to fill the cylindrical cathode.

There is effectively within the cathode cylinder a gas of the cathode composition, along with the gas composition which fills the vacuum chamber. The cathodic material will be uniformly deposited over the surface of any object or objects suspended within the cathode irrespective of shape or position. Care must be taken that the object to be coated does not touch the cathode, since this could both harm the cathode and cause nonuniformity of the coating on the article.

The control of the substrate temperature within the cylindrical cathode is important, because the substrate temperature can effect both the physical properties and chemical composition of the sputtered film. Lower substrate temperatures are needed in instances where oxidizable materials and alloys are sputtering or the sputtered film is magnetically oriented during the deposition. Higher substrate temperatures are useful where a reactive sputtered layer is formed on the substrate. Where the temperature of the substrate is held within predetermined limits, specific and uniform physical and chemical properties in the sputtered layer may be consistently obtained.

The oxidation of sputtered deposited materials at high temperatures proceeds rapidly even with the presence of only trace oxidizing impurities, e.g., oxygen and water vapor, in the chamber. Where a high purity film is desired, then, substrate temperatures must be controlled within a range that will not promote oxidation of the sputtered layer as formed. However, if an oxidized film is desired in whole or in part, this can be obtained by use of a high substrate temperature plus sufficient oxidizing reactants in the chamber. Combinations of pure and oxidized sputtered materials can be obtained by initially having a low substrate temperature which allows the formation of a pure layer of cathode material and then allowing the substrate temperature to rise whereby an oxidized layer would be formed.

In the case of alloy sputtering, nonuniformity of composition can result due to diffusion effects which are promoted at higher temperatures in the deposited layer and the cylindrical cathode. As an example, the cathode alloy composition is sputtered onto the substrate and then, while continuing to sputter, the substrate temperature rises subsantially. Diffusion of the material having the higher vapor pressure in the alloy to the surface would result. Further, if the cylindrical cathode temperature rises unduly diffusion will occur at a high rate in the cathode itself, thereby causing a materially higher concentration of the more volatile of the alloyed materials at the surface of the cathode. Sputtering under this condition results in a coating having a nonuniform alloy composition throughout its body.

The magnetic orientation of a ferromagnetic alloy during sputtering is affected by substrate temperature. The coercivity H_c of the sputtered magnetic films is sensitive to changes in film composition homogeneity and to small amounts of oxygen contamination. These variables can be controlled by substrate temperature to give films of a variety of desired coercivities.

The methods available for controlling the substrate temperature are to highly cool the article prior to entrance into the cylindrical cathode, cooling the article during sputtering and holding the cathode at a low tem-

perature to reduce radiation heating effects. The prior cooling can be accomplished by exposure to a high cooling medium such as liquid nitrogen. The article cooling during sputtering is done by circulation of the gaseous medium in the chamber, wherein the input gas is caused to flow within the cylindrical cathode for cooling purposes. Cathode cooling can be by use of a water jacket or cooling coils in contact with the external surface of the cathode.

The gas flow article cooling method operates at its highest cooling efficiency where the chamber pressure is at its highest practical pressure, since there is then the greatest possible gas flow. A compromise is then required between higher pressure and smaller diameter cathode, so that the glow discharge is maintained within the cathode.

The orientation of ferromagnetic sputtered layers during deposition on a substrate requires the application of an orienting field surrounding the substrate. The most practical method of supplying the orienting field circumferentially around a cylindrical substrate is to pass a current along the length of the substrate. The current conductor can be in the form of a wire threaded through the cylindrical substrate or a conductive coating on the external surface of the substrate. The substrate could, alternatively, be itself a conductive wire.

The following is an example in detail of the method of the present invention used to fabricate thin ferromagnetic bistable films. The example is 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 and scope of this invention.

A .030 inch outside diameter-.020 inch inside diameter glass tube was thoroughly cleaned by use of standard chromic acid solution, rinsed in distilled water and dried.

A three inch diameter cathode was made by bending a nickel-iron (81–19%) alloy sheet into a cylindrical shape and welding the ends of the sheet together with the same nickel-iron alloy. This cylindrical cathode was inserted into the chamber supported by a cradle structure as shown in the FIGURES 1 and 2.

The chamber was evacuated with a blank article placed within the cathode. A voltage was applied between the cathode and anode, and sputtering occurred with the glow confined to the cylindrical cathode. This procedure cleaned the surface of the cathode. The blank article was then removed and the prepared glass tube was placed within the cathode. An orienting copper wire of 16 mil diameter was threaded through the glass tube and connected to a D.C. voltage source. The pressure within the chamber was reduced to 6×10^{-6} millimeters of mercury. Argon gas was measured into the bell jar until the pressure within the jar was 100 ± 10 microns as measured by a thermocouple gauge. There was no cooling of either the article or the cathode in this particular example. The sputtering voltage of 420 volts was applied across the cathode and the anode and the sputtering current was 300 milliamps. The glow discharge was substantially confined to within the cylindrical cathode. The voltage was applied for a period of 25 minutes and the orienting current in the orienting wire was held at 3 amps throughout the sputtering time. It was observed during the sputtering that the glass tube substrate was stressed by the expansion of the orienting field wire through the tube and the heat in the vacuum so that the tube was bowed somewhat. The tube was cooled to room temperature and then moved from the chamber. There was a thickness of 10,700 Angstrom units of nickel-iron on the external surface of the glass substrate.

Standard B–H hysteresis loops were run on the bistable thin film deposit in the hard and easy directions by proceeding through a cycle of values for the magnetizing force—from zero to a negative maximum, and back to zero—to form a loop of flux densities. The results are shown in FIGURES 3 and 4. The hysteresis loop in the easy direction, FIGURE 3, is almost square. It is noted that the coercive force H_c in the hard direction, FIGURE 4, is of an order of 0.5 oersted. The magnetic properties of the thin film are therefore seen to be suitable for bistable magnetic switching.

The cleanliness of the novel cylindrical cathode system, together with the ability to control the temperature of the coated article, and the cathode itself during sputtering, makes a continuous cathode sputtering system now practical. There are two alternate means for moving a series of articles to be coated into the cylindrical cathode within the vacuum chamber and removing them after the application of a coating. The articles can move from outside the vacuum chamber to inside the chamber through a means that will stop any air flow into the chamber and be removed from the chamber in like fashion. The alternate is to have a dispensing means within the chamber which will upon signal deposit an article within the cylindrical cathode and upon another signal move the coated article from within the cathode. Further, means for holding at least one article within the cylindrical cathode is needed because there should be freedom of motion of the articles coated through the cathode and articles touching the cathode during sputtering would not give a uniform coating at the point of contact.

Referring now to FIGURE 5, there is shown a first continuous cathode sputtering apparatus for coating a plurality of articles. The cylindrical cathode and general auxiliary sputtering equipment is identical to that of FIGURES 1 and 2 and is therefore shown only schematically in FIGURE 5. Like numbers are used to show like structures throughout the drawings. The chamber **70** which is capable of holding a vacuum may be large enough to hold two or more cylindrical cathodes as indicated by the two cathodes **14** shown and separated by the broken lines. The chamber **70** has inlet and outlet air locks **72** and **74** respectively at opposite ends of the chamber and aligned with the open ends of the cylindrical cathodes **14**. The air locks are connected by means of vacuum lines **76** to a fast vacuum source (not shown). The fast vacuum source maintains lower pressure in the air locks than is present within the chamber **70**. This condition seals the chamber **70** from leakage of air from outside the chamber. The articles **8** to be coated are supported on wires **84**. The wires **84** with the articles **8** thereon are tautly held by upright holding means **86**. The wires together with the articles to be coated are threaded through the inlet airlock, the cylindrical cathode and the outlet airlock and secured to the holding means **86**. The clearance between the external surface of the articles to be coated and the inlet and outlet air locks is kept to a minimum. A means for continuously moving the wire **84** through the chamber **70** at a speed regulated to the amount of coating desired on the external surface of the articles **82** is provided. An example of such means is illustrated as the rack **88** and pinion **90** structure which are driven by a motor (not shown). The wire **84** should be composed of a conductive material such as copper if it is to be used as a current conductor for application of a magnetic field around the article during deposition.

FIGURE 6 shows a second continuous cathode sputtering apparatus for coating articles. The cylindrical cathode and auxiliary structures of FIGURES 1 and 2 are utilized and like numbers indicate like structures throughout the drawings. Within the vacuum chamber **92**, there is located a dispensing means **94** which holds a plurality of articles **8**. The articles **8** are illustrated as tubes with wires **98** threaded through and the wires secured to the tubes by means of a suitable welding material. A first relay **100** operates an arm **102** which acts on the notched bar **103** to progressively move the dispensing mechanism. As the dispensing mechanism moves one notch, the article **8** to be coated drops through a dispensing hole **104** and

into the cylindrical cathode **14**. One end of the threaded wire **98** rests upon the table **106**. A second relay **108** operates clamping means **110** which clamps onto the threaded wire **98** to hold the article securely within the cylindrical cathode. A suitable magnetic orienting current can also be applied to the wire **98** through the clamping means. When the required deposit has been made upon the article, the clamping means releases the wire by action of relay **108**. A third relay **112** acts in conjunction with a door **114** in table **106** as a means for removing the article from within the cathode by withdrawing the surface upon which the wire **98** is resting. The coated article then drops through hole **116** into container **118**. Then in sequence the first relay **100** acts to move another article through the hole **104** and into the cylindrical cathode and the procedure continues as above described.

The invention is useful in the fabrication of a wide variety of coated articles. The classes of materials wherein the novel sputtering method and apparatus of this invention is superior to other deposition techniques include alloys, metals having low vapor pressures, and expensive materials. The sputtering of alloys is preferred to vacuum evaporation techniques in almost all cases except where the vapor pressures of the alloyed materials are close together. Metals that are hard to evaporate; such as platinum, iridium, tantalum, tungsten, zirconium, and molybdenum, are difficult subjects for vacuum evaporation, but easy subjects for the cathode sputtering technique of the present invention. Materials which are expensive, such as gold or palladium, can now be deposited by means of the present invention without the expensive waste of material.

The invention thus provides an improved method and apparatus for depositing films by cathode sputtering. The procedures teach how a wide variety of coating materials can be uniformly deposited as to both thickness and composition over the surface of articles irrespective of their shapes. The method and apparatus provides further for high sputtering rates, while making such efficient use of the cathodic source material that it is now practical to sputter highly expensive materials. Further, the cleanliness of the system makes its adaption to continuous and mass production techniques now possible.

While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details 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;
a substantially cylindrical cathode having at least one open and and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode; a shield disposed about said cathode;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

2. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a substantially cylindrical cathode having at least one open end and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode;
means for cooling said cathode; a shield disposed about said cathode;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

3. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical cathode having at least one open end and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode;
said anode and said means for supporting being external to said cathode;
means for cooling said cathode; a shield disposed about said cathode;
means for cooling said article;
means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode;
and means for applying an orienting field to said article during said glow discharge.

4. Apparatus for coating a hollow article comprising:
a chamber capable of holding a high vacuum;
a cylindrical cathode having at least one open end and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode;
said anode and said means for supporting being external to said cathode;
means for cooling said cathode; a cylindrical shield disposed about said cathode;
means for cooling said article;
a current conductor threaded through said hollow article;
means for applying a current through said conductor to produce a magnetic orienting field around said article;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

5. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical cathode having at least one open end and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber; a shield disposed about said cathode;
means for supporting said article within said cylindrical cathode;
said anode and said means for supporting being external to said cathode;
means for circulating a gas having a low partial pressure in said chamber through said chamber for article cooling;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

6. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode;
said anode and said means for supporting being external to said cathode; a shield disposed about said cathode;
a gas input tube positioned in said chamber for directing gas into the inner space of said cathode;
an output port in said chamber connected to a vacuum source;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

7. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode;
said anode and said means for supporting being external to said cathode;
a cooling jacket means surrounding said cathode; a shield disposed about said cooling jacket;
coolant input and output means connected to said jacket means for circulating coolant through said jacket means;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

8. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode;
said anode and said means for supporting being external to said cathode;
a cooling jacket means surrounding said cathode;
coolant input and output means connected to said jacket means for circulating coolant through said jacket means;
said jacket means being contiguous with the external surface of said cathode;
the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode; a shield disposed about the exterior surface of said cooling jacket means;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

9. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode;
said anode and said means for supporting being external to said cathode;
a gas input tube positioned in said chamber for directing gas into the inner space of the said cathode;
an output port in said chamber connected to a vacuum source;
a cooling jacket means having coolant input and output ports surrounding said cathode;
means connected to said input and output ports for circulating coolant through said jacket means;
a cylindrical shield adjacent to and closely spaced from the external surface of said jacket means;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

10. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for supporting said article within said cylindrical cathode;
said anode and said means for supporting being external to said cathode;

means for injecting a gas having a low partial pressure in said chamber through said chamber for cooling said article;
a cooling jacket means having coolant input and output ports surrounding said cathode;
means connected to said input and output ports for circulating coolant through said jacket means;
said jacket means being contiguous with the external surface of said cathode;
the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode;
a cylindrical shield adjacent to and spaced from the external surface of said jacket means;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

11. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a base plate;
a cylindrical open ended cathode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means secured to said base plate for supporting said cathode; a shield disposed about said cathode;
an anode adjacent to each open end of said cylindrical cathode and physically secured to said base plate;
attachment means on each of said anodes for supporting said article within said cylindrical cathode;
and means for applying a voltage across said cathode and said anodes to cause a glow discharge within said cylindrical cathode.

12. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a base plate;
a cylindrical open ended cathode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means secured to said base plate for supporting said cathode;
an anode adjacent to each open end of said cylindrical cathode and physically secured to said base plate;
attachment means on each of said anodes for supporting said article within said cylindrical cathode;
a cylindrical ground shield adjacent to and closely spaced from the external surface of said cathode;
means for applying a voltage across said cathode and said anodes to cause a glow discharge within said cylindrical cathode;
and means for applying an orienting field to said article during said glow discharge.

13. Apparatus for coating articles comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
a shield disposed about said cathode;
means for moving said articles into and removing them from said cylindrical cathode at predetermined times;
means for holding at least one of said articles at a given time within said cylindrical cathode;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

14. Apparatus for coating articles comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
a shield disposed about said cathode;

said chamber having inlet and outlet air locks at opposite ends of said chamber and aligned with the open ends of said cylindrical cathode;
means for successively passing a plurality of articles through said inlet air lock, said cylindrical cathode and said outlet air lock;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

15. Apparatus for coating hollow articles comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
a shield disposed about said cylindrical cathode;
said chamber having inlet and outlet air locks at opposite ends of said chamber and aligned with the open ends of said cylindrical cathode;
a wire having said hollow articles threaded thereon and secured thereto passing through said inlet air lock, said cylindrical cathode and said outlet air lock;
means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode;
and means for continuously moving said wire through said chamber at a speed regulated to the amount of coating desired on the external surface of said articles.

16. Apparatus for coating articles comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
a shield disposed about said cathode;
means for intermittently dispensing said articles into said cylindrical cathode;
means for holding at least one of said articles at a given time within said cylindrical cathode;
means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode;
and means for removing said at least one article from within said cathode after the desired deposit thickness has formed upon the external surface of said article.

17. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
a cooling jacket means surrounding said cathode;
coolant input and output means connected to said jacket means for circulating coolant through said jacket means;
said jacket means being contiguous with the external surface of said cathode;
the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode;
a cylindrical shield disposed about said cooling jacket means;
means for moving said articles into and removing them from said cylindrical cathode at predetermined times;
means for holding at least one of said articles at a given time within said cylindrical cathode;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

18. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
means for injecting a gas having a low partial pressure in said chamber through said chamber for cooling said article;
a cooling jacket means having coolant input and output ports surrounding said cathode;
means connected to said input and output ports for circulating coolant through said jacket means;
said jacket means being contiguous with the external surface of said cathode;
the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode;
a cylindrical shield adjacent to and spaced from the external surface of said jacket means;
means for moving said articles into and removing them from said cylindrical cathode at predetermined times;
means for holding at least one of said articles at a given time within said cylindrical cathode;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

19. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
a cooling jacket means surrounding said cathode;
coolant input and output means connected to said jacket means for circulating coolant through said jacket means;
said jacket means being contiguous with the external surface of said cathode;
the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode;
a shield disposed about the exterior surface of said cooling jacket;
said chamber having inlet and outlet air locks at opposite ends of said chamber and aligned with the open ends of said cylindrical cathode;
means for successively passing a plurality of articles through said inlet air lock, said cylindrical cathode and said outlet air lock;
and means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode.

20. Apparatus for coating an article comprising:
a chamber capable of holding a high vacuum;
a cylindrical open ended cathode and an anode positioned within said chamber;
said cathode being substantially smaller than said chamber;
a colling jacket means surrounding said cathode;
coolant input and output means connected to said jacket means for circulating coolant through said jacket means;
said jacket means being contiguous with the external surface of said cathode;
the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode;
a shield disposed about said cooling jacket means;
said chamber having inlet and outlet air locks at opposite ends of said chamber and aligned with the open ends of said cylindrical cathode;

a wire having said hollow articles threaded thereon and secured thereto passing through said inlet air lock, said cylindrical cathode and said outlet air lock;

means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode;

and means for continuously moving said wire through said chamber at a speed regulated to the amount of coating desired on the external surface of said articles.

21. Apparatus for coating an article comprising:

a chamber capable of holding a high vacuum;

a cylindrical open ended cathode and an anode positioned within said chamber;

said cathode being substantially smaller than said chamber;

means for injecting a gas having a low partial pressure in said chamber through said chamber for cooling said article;

a cooling jacket means having coolant input and output ports surrounding said cathode;

means connected to said input and output ports for circulating coolant through said jacket means;

said jacket means being contiguous with the external surface of said cathode;

the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode;

a cylindrical shield adjacent to and spaced from the external surface of said jacket means;

said chamber having inlet and outlet air locks at opposite ends of said chamber and aligned with the open ends of said cylindrical cathode;

a wire having said hollow articles threaded thereon and secured thereto passing through said inlet air lock, said cylindrical cathode and said outlet air lock;

means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode;

and means for continuously moving said wire through said chamber at a speed regulated to the amount of coating desired on the external surface of said articles.

22. Apparatus for coating an article comprising:

a chamber capable of holding a high vacuum;

a cylindrical open ended cathode and an anode positioned within said chamber;

said cathode being substantially smaller than said chamber;

a cooling jacket means surrounding said cathode;

coolant input and output means connected to said jacket means for circulating coolant through said jacket means;

said jacket means being contiguous with the external surface of said cathode;

the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode;

a shield disposed about said cooling jacket means;

means for intermittently dispensing said articles into said cylindrical cathode;

means for holding at least one of said articles at a given time within said cylindrical cathode;

means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode;

and means for removing said at least one article from within said cathode after the desired deposit thickness has formed upon the external surface of said article.

23. Apparatus for coating an article comprising:

a chamber capable of holding a high vacuum;

a cylindrical open ended cathode and an anode positioned within said chamber;

said cathode being substantially smaller than said chamber;

means for injecting a gas having a low partial pressure in said chamber through said chamber for cooling said article;

a cooling jacket means having coolant input and output ports surrounding said cathode;

means connected to said input and output ports for circulating coolant through said jacket means;

said jacket means being contiguous with the external surface of said cathode;

the cooling jacket surface contiguous to and sides substantially perpendicular to said cathode being composed of essentially the identical material of said cathode;

a cylindrical shield adjacent to and spaced from the external surface of said jacket means;

means for intermittently dispensing said articles into said cylindrical cathode;

means for holding at least one of said articles at a given time within said cylindrical cathode;

means for applying a voltage across said cathode and said anode to cause a glow discharge within said cylindrical cathode;

and means for removing said at least one article from within said cathode after the desired deposit thickness has formed upon the external surface of said article.

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