

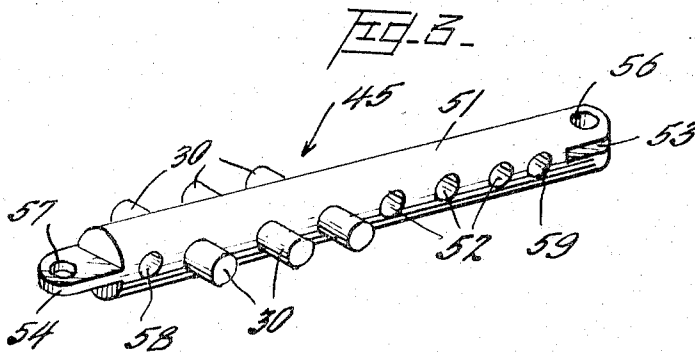
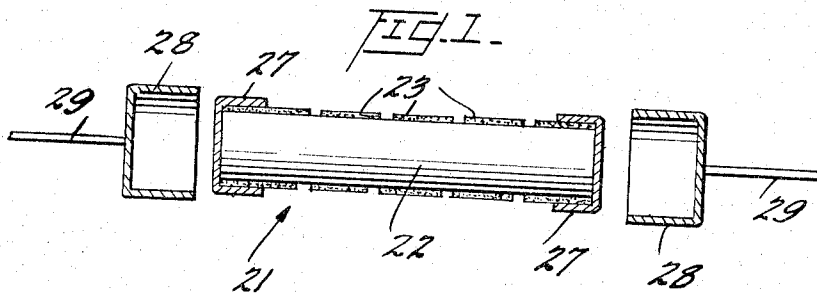
April 18, 1967

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G. LUNSFORD
METHOD AND APPARATUS FOR CATHODE SPUTTERING USING
A CYLINDRICAL CATHODE

3,314,873

3 Sheets-Sheet 1



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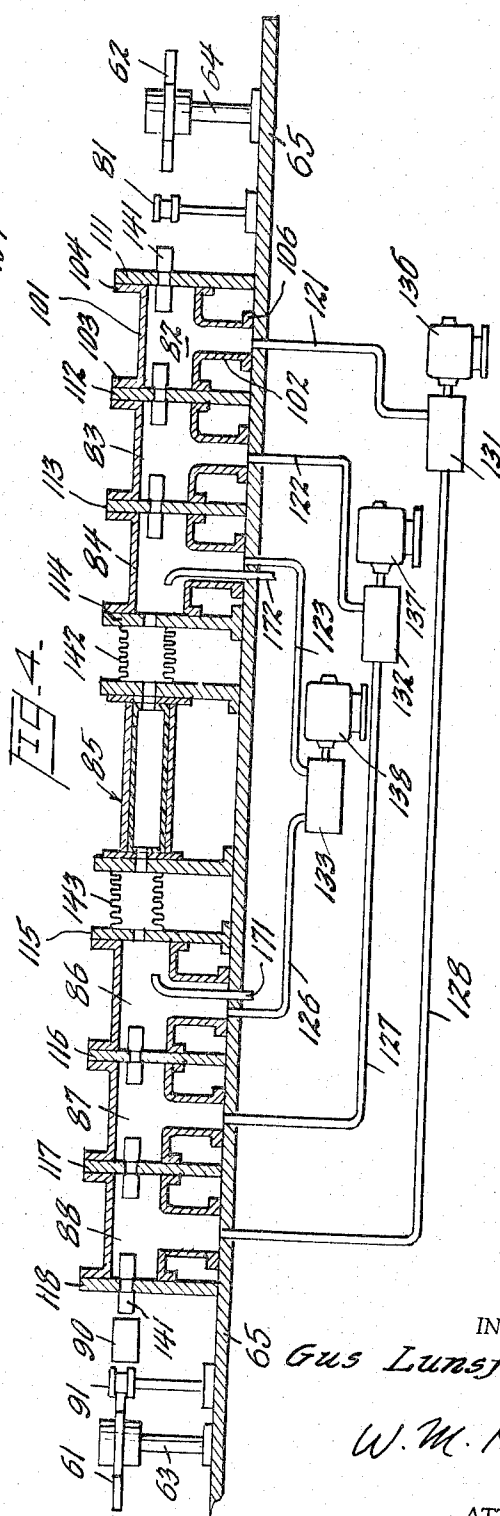
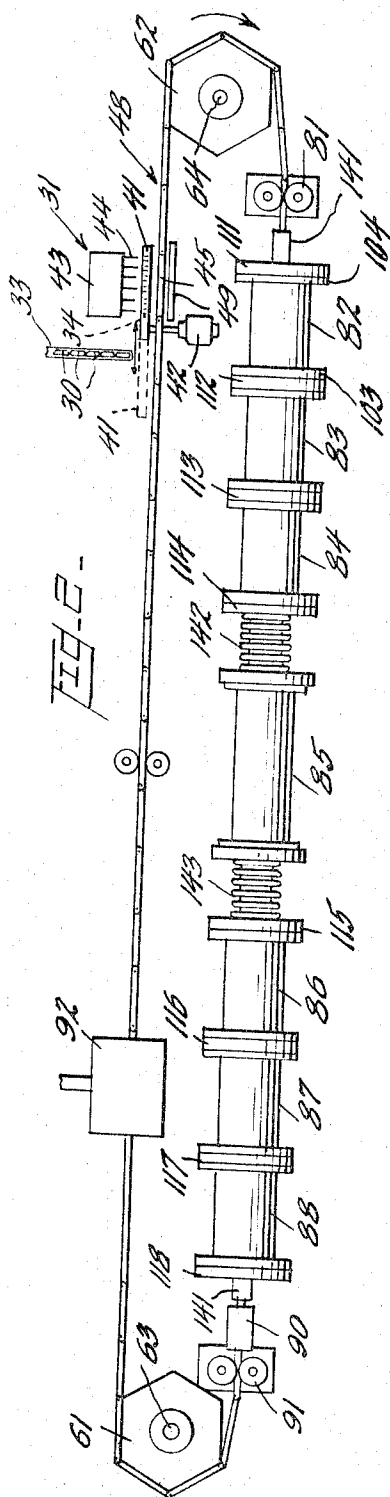
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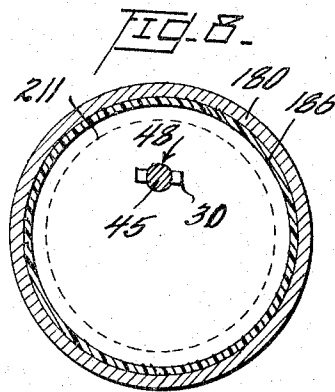
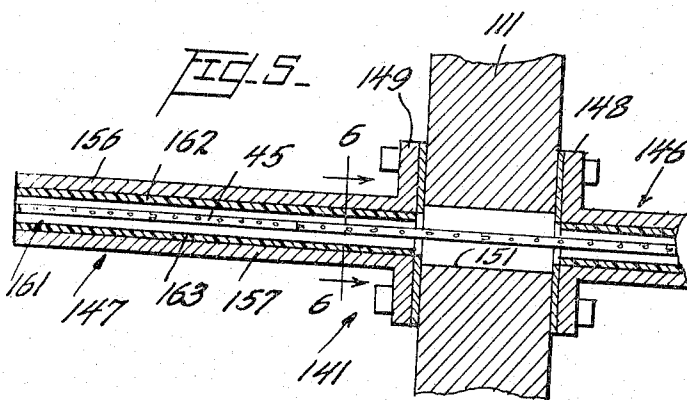
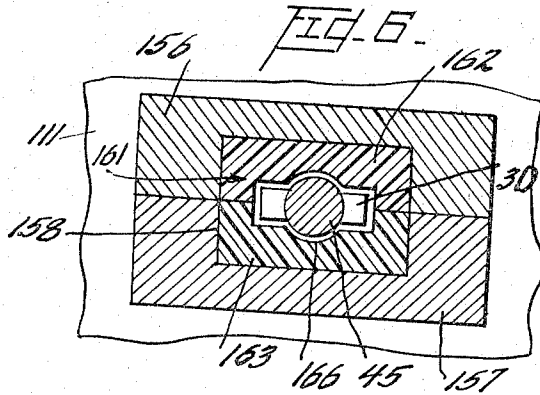
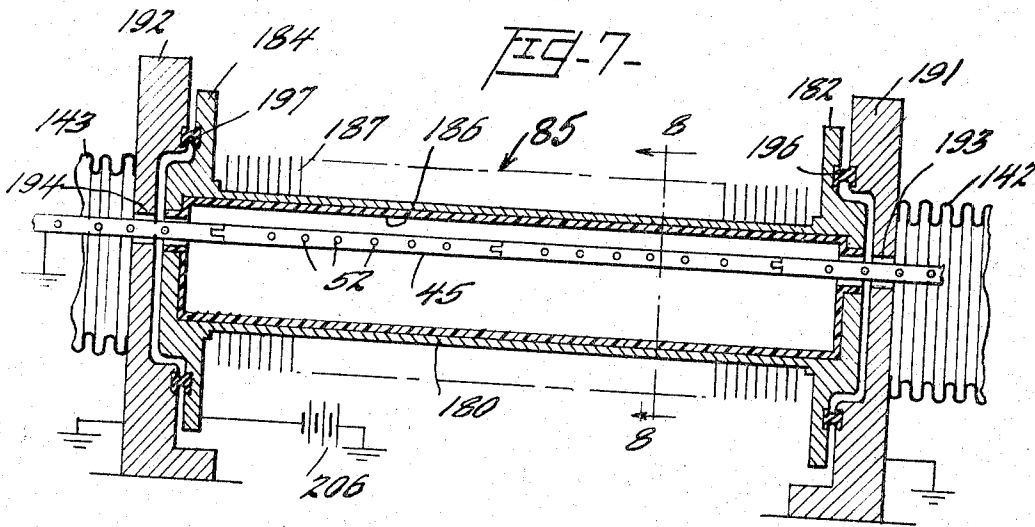
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3 Sheets-Sheet 3



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METHOD AND APPARATUS FOR CATHODE SPUTTERING USING A CYLINDRICAL CATHODE

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6 Claims. (Cl. 204—192)

This invention relates to a method of and apparatus for sputtering and more particularly to an in-line cathodic sputtering method and apparatus for continuously and uniformly depositing electrically conductive coatings on electrical components. This invention finds special utility in sputtering conductive terminations on resistors of the type including a non-conductive core on which a conductive film is deposited, for example, a conventional deposited carbon resistor.

The usual cathodic sputtering apparatus utilized in coating an article, such as a resistor, with a film of metal, consists of some type of stationary anode and cathode mounted within an evacuated bell jar which defines a sputtering chamber. For example, see U.S. Patent 3,039,952. The productive output of this type of apparatus is limited due to several, inherent physical characteristics of such apparatus. First, the bell jar sputtering chamber does not conveniently accommodate an efficient system for introducing and retrieving an article from the chamber without destroying the vacuum. Thus, rapid, continuous operation of bell jar sputtering chamber is difficult to attain. Secondly, the bell jar system, and like systems, place serious limitations on the configuration of the cathode and anode which may be employed in a sputtering chamber of practical size. Increased production on such equipment, involves costly multiplication of bell jars, each with separate cathode, anode, evacuation, and article supporting facilities. Finally, the usual cathode and anode configurations in bell jar systems produce an ion field which is suitably uniform in so limited an area as to render batch sputtering impractical. The usual bell jar system is designed to accommodate a single article, thus reducing the productivity of the apparatus.

It is an object of the present invention to provide a new and improved cathodic sputtering machine.

It is another object of this invention to provide an improved sputtering machine and method for continuously and uniformly depositing conductive material on a plurality of components passing therethrough.

It is a further object of this invention to provide a new and improved tubular sputtering cathode and special anode configuration suitable for coating a serial procession of workpieces.

It is another object of this invention to provide a sputtering chamber which is effectively of infinite electrical length and which provides uniform deposition of metal on a workpiece.

It is another object of this invention to provide new and improved apparatus for continuously conveying a plurality of articles through an evacuated chamber for coating the articles with a film of material.

With these and other objects in mind, this invention contemplates a sputtering method and apparatus for coating articles with material. For example, the articles may be deposited carbon resistor blanks, and gold the material to be coated thereon to form a termination. The machine includes a tubular cathode of the material to be sputtered and means for supporting an article to be coated within the cathode. The supporting means, may, for example, comprise a continuous conveyor.

Also provided are means for causing the material of the cathode to sputter and coat the supported article.

In a specific embodiment of this invention, the means for supporting articles to be coated may comprise a conveyor which also serves as the anode for causing the cathode to sputter. In a further refinement, these supporting means may perform four functions, that of: a conveyor, an anode, a mask for preventing unwanted sputtering, and a seal to prevent undesirable leakage of gases into the tubular cathode.

Other objects and advantages of the invention will become apparent from the following detailed description and the accompanying drawings illustrating a specific embodiment thereof, in which:

FIG. 1 is an exploded, sectional view of a deposited carbon resistor, the terminations of which have been produced by a machine according to this invention;

FIG. 2 is a plan view of an embodiment of this invention showing a sputtering chamber, a serially connected plurality of locks sealing the ends of the chamber, and a chain type conveying system extending through the chamber and locks;

FIG. 3 illustrates one link of the conveyor chain shown in FIG. 2, partially loaded with articles to be coated;

FIG. 4 is an elevation, partially in section, of the apparatus of FIG. 2, showing details of the locks, the sputtering chamber, and apparatus for evacuating the locks and chamber;

FIG. 5 is an enlarged, fragmentary, sectional view of one of the locks illustrated in FIG. 4 showing a lock including lined sealing tubes through which articles to be coated are conveyed;

FIG. 6 is an enlarged, sectional view taken on line 6—6 of FIG. 5 illustrating the cross section of a sealing tube as it conforms to an article to be coated which is supported on a link of the conveyor chain;

FIG. 7 is an enlarged cross section of the sputtering chamber shown in FIGS. 2 and 4; and

FIG. 8 is a sectional view taken on line 8—8 of FIG. 7 showing details of the cathode as an article to be coated passes therethrough.

FIG. 1 illustrates a deposited carbon resistor 21, the terminations of which may be expeditiously produced using a machine according to this invention. Resistor 21 includes a ceramic core 22 on which a conductive carbon coating 23 is deposited. The above-mentioned terminations, terminations 27, gold in this instance, are sputtered on the end portions of the resistor in contact with carbon coating 23. A pair of metal caps 28 are fixed on the ends of the resistor in contact with terminations 27, and a pair of leads 29 are welded or otherwise fixed in electrical contact with caps 28. Finally, a spiral cut is made in the carbon coating 23, thereby determining the electrical resistance between the leads 29, and the resulting resistor component is encapsulated. The purpose of terminations 27 is to make intimate electrical connection to the deposited carbon coating 23 and to provide a suitable highly conductive surface on which to fix caps 28.

Hereinafter, a ceramic core 22 having a carbon coating 23 deposited thereon will be referred to as a core 30.

As seen in FIG. 2, apparatus according to this invention includes a feeding station generally indicated by the number 31. Cores 30 are serially fed through a feed tube 33 to be inserted, one at a time, into apertures 34 in an elongated shuttle 41. A reversible motor 42 is connected to drive a gear (not shown) which engages a track (not shown) on the underside of shuttle 41. Energizing the motor to turn alternately in opposite directions causes shuttle 41 to reciprocate from the position shown in phantom (FIG. 2) to that shown in solid lines. With each rightward movement of the shuttle, a group

of cores 30 is transported from feed tube 33 into alignment with a pusher 43. Pusher 43 is provided with a plurality of pins 44 which align with apertures 34 when shuttle 41 is in its rightmost position (FIG. 2). Actuation of pusher 43 drives the group of cores from shuttle 41 into transverse bores in a link 45 of a conveyor chain 48. A back-stop 49 insures proper positioning of the cores in the link 45.

Each link 45 in chain 48 is identical to that illustrated in FIG. 3. Link 45 includes an elongated body 51 having a plurality of parallel, longitudinally spaced, transverse bores 52 therein. The sides of these bores 52 provide a means for uniformly orienting the cores 32 and provide the cores with uniform spacing along body 51. Body 51 is milled to define a groove 53 at one end and a tongue 54 at the other end thereof. Vertical bores 56 and 57 extend through the bifurcations defining groove 53 and through tongue 54, respectively. Each link 45 is provided with transverse aligning bores 58 and 59 engageable with aligning pins on pusher 43 to insure precise alignment of pusher 43 with the link. Chain 48 is made up of links 45 placed end to end in tongue-in-groove relation with wrist pins (not shown) in the bores 56 and 57.

Chain 48 forms a closed loop which passes over hexagonal idler wheel 61 and is tensioned by idler wheel 62. Each of the six sides of the idler wheels is of a length to accommodate a link 45 and is relieved to accommodate cores 30. The idler wheels 61 and 62 are fixed to shafts 63 and 64, respectively, which are mounted for rotation on a base 65 (FIG. 4).

Since the above-described feeding operation occurring at feeding station 31 is intermittent, it is necessary to impart an intermittent, stop-pause-go, motion to chain 48 in time with the operation of pusher 43. Such a drive may be accomplished in any of many known ways. A very desirable drive is one which successively engages each link 45 and moves it precisely the length of the link, then returns to engage the next link and move it the same distance, and so on. Control means (not shown) coordinate feeding operations at feeding station 31 with the intermittent drive, so that each link 45 pauses for loading in alignment with pusher 43.

Chain 48 loaded with cores 30 passes about idler wheel 62 between the rolls of roller guide 81, through a series of vacuum chambers 82, 83, and 84; through sputtering chamber 85; and through vacuum chambers 86, 87, and 88. On leaving vacuum chamber 88, the chain passes through unloading station 90 where the cores 30 having terminations 27 (FIG. 1) sputtered thereon are unloaded in preparation for the above-outlined subsequent fabricating operations. The chain 48 is then guided by the rolls of roller guide 91 onto idler wheel 61. From the idler wheel 61, the chain passes through a safety unloading and chain cleaning station 92, thence to feeding station 31 where it is reloaded with cores 30.

Referring to FIG. 4, each of the vacuum chambers 82-84 and 86-88 is identical to vacuum chamber 82 and includes an elongated cylindrical chamber 101 having a hollow stem 102 extending radially therefrom. Chamber 101 is provided at its ends with flanges 103 and 104, and stem 102 is provided with flange 106. Flanges 103 and 104 are sealed against partitions 111-118, respectively. Each stem 102 is sealed by means of its flange 106 on base 65.

Base 65 is apertured at each of the points over which a stem 102 is sealed. Tubes 121, 122, and 123 extend through these apertures to communicate with vacuum chambers 82, 83, and 84, respectively. Likewise, tubes 126, 127, and 128 communicate with vacuum chambers 86, 87, and 88, respectively. Tubes 121 and 128 are connected to a vacuum pump 131; tubes 122 and 127 are connected to a vacuum pump 132, and, tubes 123 and 126 are connected to a vacuum pump 133. Pumps 131-133 are powered by motors 136, 137, and 138, respectively. Pump 131 is adjusted to produce a high degree of evacuation in the vacuum chambers to which it is connected;

pump 132 a somewhat higher degree of evacuation in the chambers to which it is connected; and pump 133 a still higher degree of evacuation in its chambers.

As seen in FIG. 4, each of partitions 111, 112, and 113, 116, 117, and 118 has a lock 141 extending there-through. Partitions 114 and 115 are apertured to communicate with the interior of accordion couplings 142 and 143, respectively, and the accordion couplings are sealed to sputtering chamber 85. Thus, the vacuum chambers communicate with one another, and vacuum chambers 82 and 88 communicate with the atmosphere only through locks 141. Also, the sputtering chamber is isolated from the atmosphere by these locks.

Referring to FIGS. 5 and 6, each lock 141 comprises a pair of symmetrically arranged lock tubes 146 and 147 provided, respectively, with flanges 148 and 149. The lock tubes are sealed by means of these flanges over an aperture in each partition, shown, for example, as aperture 151 in partition 111. The length of each lock 141 is preferably as long as a link 45. As a minimum it should be sufficiently long as to bridge a plurality of bores 52 in a link 45.

As best seen in FIG. 6, each lock tube 146 and 147 is made up of an upper channel 156 and a lower channel 157 which together define a tunnel 158 of rectangular cross section. A liner 161 is placed within tunnel 158. The liner, formed by mating upper and lower halves 162 and 163, is made of fluorocarbon material such as Teflon, which has a self-lubricating quality. The halves of liner 161 together define a passage 166, shaped to conform to the cross section of a link 45 having cores 30 loaded therein. In this example, passage 166 has a friction fit about chain 48 and provides a .003 to .005 inch clearance about the core ends.

Referring to FIG. 7, sputtering chamber 85 includes a hollow cylindrical cathode 180 sealed at its ends by a pair of end caps 182 and 184. In this example, the cathode has an inside diameter of approximately 1 7/8 inches and is about 10 inches long. The cathode is provided with a liner 186 of the material to be sputtered, gold in this example, which covers its entire interior and extends through apertures in end caps 182 and 184. Cooling fins 187 project radially from the cathode. A pair of shields 191 and 192 are spaced symmetrically about end caps 182 and 184, respectively. A pair of ring seals 196 and 197 of a resilient, electrically insulating, heat resistant material, such as silicone rubber, seal end caps 182 and 184 within shields 191 and 192. The ring seals provide electrical insulation and prevent the intrusion of atmosphere between the caps and the shields.

Accordion coupling 142 is sealed over an aperture 193 in shield 191. Likewise, accordion coupling 143 is sealed over an aperture 194 in shield 192. These couplings, being freely extendible, accommodate any thermal expansion of the sputtering chamber, and facilitate access to the interior of sputtering chamber 85.

Referring to FIG. 7, cathode 180 may be negatively biased by potential source 206, the positive side of which is grounded. Chain 48 and shields 191 and 192 are also grounded. Thus, cathode 180 may be maintained at a negative potential relative to the chain 48 and to the shields 191 and 192, both the chain and the shield serving as anodes.

The interior of cathode 180 may be sufficiently evacuated by means of the above-described pumps and maintained at a sufficient negative potential relative to chain 48 to create a cathode dark space 211 of finite thickness (FIG. 8). Chain 48, loaded with cores 30 passes through cathode 180 at a point removed from the center of the cathode and spaced from liner 186 by a margin greater than the thickness of dark space 211.

While the cores 30 are within the sputtering chamber, material from the liner 186 sputters onto the cores in the areas not masked by links 45.

After terminations 27 have been sputtered on the cores,

the cores pass through accordion coupling 143, and through vacuum chambers 86, 87, and 88 to be automatically unloaded at unloading station 90.

Operation

The general mode of operation of a machine according to this invention has been described above in tracing the course in cores 30 from feeding station 31 to unloading station 90. Certain details of the operation of this machine require further explanation.

In order to prepare the above-described machine for operation, it is necessary to take certain steps. Motors 136, 137, and 138 must be energized to drive pumps 131, 132, and 133 and evacuate the vacuum chambers and sputtering chamber to the proper degree. Initially, vacuum chambers 84 and 86 should be maintained at a pressure on the order of one micron of mercury; vacuum chambers 83 and 87 on the order to two microns of mercury; and vacuum chambers 82 and 88 on the order of five millimeters of mercury.

Potential source 206 must be activated to charge cathode 180 to potential sufficient to cause cathodic sputtering. Using a cathode of the dimensions indicated above (inside diameter about $1\frac{7}{8}$ inches, length about 10 inches), this may be accomplished by charging the cathode to a potential of 600 volts relative to shields 181 and 192 and chain 48.

With the cathode potential so adjusted, argon is permitted to leak through conduits 171 and 172 (FIG. 4) until sputtering occurs on the surface of liner 186. The drive for chain 48, feeding station 31, and unloading station 92 are activated and the above-described core feeding operation commences carrying cores 30 through the vacuum chambers, locks 141, and sputtering chamber 85.

When a link 45 enters a lock 141 (FIG. 6), passage 166 very closely surrounds the contour of the link and the core (in the above example, friction fit about the chain, and a .003-.005 inch clearance about the core. Such close clearance provides a blocking action which inhibits the flow of gas through the lock tube. It does this by sharply blocking passage 166 and also by creating a turbulence about the core and link which further inhibits the flow of gases through passages 166. Since the length of the lock tube is greater than the spacing of the cores 30 along a link 45, the introduction of each successive core within passage 166 further tends to seal the passage 166 against the flow of gases by blocking the passage and by increasing the above-mentioned turbulent effect. In a link 45 carrying a large number of cores, this combined blocking and turbulence creation provides especially effective seal against the escape of gases. Increased turbulence, and hence reduction of gas flow, is accomplished at each partition 111-118 due to the effect of passage 151 (FIG. 5) which is larger in diameter than passage 166.

Each link 45 performs at least four separate functions in cooperation with the elements of this machine. It serves as a conveyor of cores 30, an anode in the sputtering operation, a mask to prevent coating the cores except on preselected areas; and means for preventing the intrusion of gases through locks 141.

Cylindrical cathode 180 surrounds the cores supported on chain 48. This configuration permits the achievement of sputtering many times more efficient than a conventional, plate type cathode. Also, since sputtering material is directed inwardly from the walls of the cathode, the deposition of sputtered material on the cores is very uniform. Furthermore, it is unnecessary to revolve the cores in order to achieve uniform coating thereon.

While it would be feasible to have the cores pass through the center of the cathode rather than along the off center path as described above, it is advantageous to use an off center path (FIG. 8) for a number of reasons. The focusing effect of the cylindrical cathode would cause extreme heating of the anode and the core if the latter

passed through the center of the cathode. Such heating, if sufficiently intense, may actually prevent effective coating by sputtering. In using such a cylindrical cathode, there is an area between the center of the cathode and the inner margin of the cathode dark space where maximum deposition occurs. This point has been determined experimentally and is reflected in spacing the path of chain 48 from the center of cathode and from the dark space 211 as shown in FIG. 8.

Since the entire interior of the sputtering chamber, accordion couplings, and vacuum chamber is in a highly evacuated condition, and since the cathode is charged negatively relative to the remaining portions of the machine, there would, in the absence of shields 191 and 192, be a tendency to sputter and deposit material at points other than within the cathode. Shields 191 and 192 are placed sufficiently close to the cathode to be within the cathode dark space thereof. This effectively prevents the sputtering of material outside the confines of the cathode.

It is to be understood that the above-described arrangement of apparatus and construction of elemental parts are simply illustrative of an application of the principles of this invention and that many other modifications may be made without departing from the invention.

What is claimed is:

1. A method of coating articles by cathodic sputtering which comprises the steps of:

applying a sputtering potential between a cylindrical cathode having a circular cross-section and a major axis and to an anode positioned therewithin, and moving articles to be coated through said cathode along a path which is parallel to and removed from both said major axis and the walls of said cathode so that no portion of said articles impinges upon said major axis.

2. A method of coating articles by cathodic sputtering which comprises the steps of:

applying a sputtering potential to a cylindrical cathode having a circular cross-section and a major axis and to a movable conveyor positioned therewithin, mounting articles on said conveyor, moving said conveyor and said mounting articles through said cathode along a path which is parallel to and removed from said major axis and the walls of said cathode, and maintaining said moving conveyor so that no portion of said articles impinges upon said major axis.

3. A method of coating articles by sputtering utilizing a cylindrical cathode having a circular cross-section and a major axis which comprises the steps of:

mounting articles to a movable conveyor, positioning said conveyor within said cathode parallel to said major axis so as to preclude the impingement of said mounted articles upon said major axis, moving said conveyor through said cathode, and applying a sputtering potential to said cathode and to said conveyor whereby heating of said articles is minimized and the sputtering rate is maximized.

4. In a sputtering machine for coating articles with material, a tubular cathode of the material to be sputtered, the cathode having a circular cross section and a major axis,

an anode positioned within the cathode,

means for moving the anode along a predetermined longitudinal path through the cathode, the path being parallel to and removed from both said major axis and the walls of said cathode so that said articles and said anode are separated from said major axis, support means longitudinally spaced along the anode for maintaining articles to be coated in uniform orientation and for masking portions of the articles, and

means for cathodically sputtering said material to coat unmasked portions of the oriented articles.

5. In a sputtering machine for coating articles with material,

- (a) a sputtering chamber open on at least one end,
- (b) a tubular cathode of said material to be sputtered within said chamber, the cathode having a circular cross section and a major axis, 5
- (c) means for supporting articles to be coated within said cathode and for sealing said open end of said chamber, said supporting and sealing means including,

- (1) a conveyor extending through said cathode for transporting a plurality of said articles along a predetermined path in a uniformly oriented configuration spaced along said path, the path being longitudinal and parallel to and removed from both said major axis and the walls of said cathode so that no part of said articles or of said supporting means impinges upon said major axis, and 10
- (2) a tube of length greater than the article spacing maintainable by said conveyor, said tube defining a passage which surrounds said conveyor and has a cross section corresponding to the cross section taken through both the conveyor and an article loaded therein, and 15

- (d) electric potential-producing means, including said cathode and said conveyor, for impressing a negative potential on said cathode and a positive potential on said conveyor to cathodically sputter said material and coat said supported articles. 20

6. In a sputtering machine for coating articles with material,

- (a) a sputtering chamber opened at both ends, said chamber containing a cylindrical cathode of the material to be sputtered, the cathode having a circular cross section and a major axis, 25
- (b) at least one vacuum chamber positioned at and connected to one end of said sputtering chamber,
- (c) at least one vacuum chamber positioned at and connected to the other end of said sputtering chamber, 30
- (d) means including an anode and said cathode, for producing a cathode dark space having a predetermined thickness dimension within said cathode, said anode including a conveyor extending through said 35

cylindrical cathode and through said vacuum chambers for

- (1) transporting said articles in a uniformly oriented configuration spaced along a path, said path being removed from said major axis of said cathode and at a distance from the walls of said cathode greater than said predetermined thickness dimension so that said articles are transported parallel to said major axis and so that no portion of said articles or of said anode impinges upon said major axis, and
- (2) masking portions of said articles, and
- (c) a series of locks sealing each of said vacuum chambers, each lock including a tube having a length greater than the spacing between said articles, said tube defining a passage which surrounds said conveyor and has a cross section corresponding to the cross section taken through both the conveyor and an article loaded therein.

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