

# PATENT SPECIFICATION (11)

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## (54) IMPROVEMENTS IN OR RELATING TO THE COATING OF WORKPIECES

(71) We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195, Broadway, New York City, New York State, United States of America, a Corporation organised and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to methods of coating workpieces, e.g. by sputtering.

In the manufacture of many electronic or electrical components, such as integrated circuits, thin film tantalum nitride resistors, tantalum oxide capacitors, etc., there is a need to deposit metallic films on substrates. Materials such as gold, tantalum or tantalum nitride may be deposited on ceramic or glass substrates by a sputtering process and then etched or otherwise fabricated into the circuits and/or components. In sputtering, a cathode may be constructed of tantalum or a base metal with a tantalum coating and this cathode is subjected to a high voltage in an inert atmosphere such as argon, where the argon is ionized to bombard the exposed tantalum surface and dislodge atoms or clusters of atoms of tantalum which are deposited on the substrate.

Many manufacturing facilities have been developed for depositing thin films of metal on substrates. In one known open end facility, the substrates are advanced through a series of individually pumped chambers of successively reduced pressure until the substrates enter a vacuum chamber where the sputtering takes place. In another known continuous sputtering apparatus, the substrates are advanced through a series of locks which are successively evacuated and then the substrate enters a vacuum chamber to receive a sputtered deposit of metal. Even the sputtering of a relatively thin film takes considerable time; hence, these known linear facilities are necessarily slow because

so few substrates are being sputtered at a time.

In order to increase the number of substrates that are receiving a sputtered deposition, a bell jar arrangement may be utilized. In this arrangement substrates are positioned within the bell jar in a circular array about a centrally disposed cathode so that all substrates simultaneously receive a sputtered deposit of metal. This process does not lend itself to continuous operation in that the bell jar has to be pumped down for each batch of processed substrates. Further, in this process, the substrates are of a planar construction and receive non-uniform deposits of metal; more metal being deposited in the centre area of each substrate due to the closer proximity of the centre area to the centrally disposed cathode.

Many other problems exist in the sputtering of metal onto substrates, such as the need to outgas both the substrates and the substrate holders, the uniform distribution of both inert gasses and reactive gasses introduced into the sputtering atmosphere, and the dissipation and control of heat.

According to this invention there is provided a method of coating workpieces wherein an enclosure containing a source of coating material is maintained at a controlled atmosphere different from the ambient atmosphere, a plurality of workpieces each having a planar surface are entered into said enclosure substantially without disruption of said controlled atmosphere, said workpieces are advanced along a closed path about said source and are coated, the central portion of each of said surfaces being shielded from said source of coating material for part of the time during which coating occurs, and said workpieces are subsequently removed from said enclosure substantially without disruption of said controlled atmosphere.

Said coating material may be sputtered onto said workpieces.

Said source may include a cylindrical

cathode dimensioned and arranged such as to provide a substantially uniform coating on said planar surfaces.

5 Said source may be a cylindrical, hollow cathode, cooling fluid may be circulated within said cathode to dissipate heat therefrom, and cooling fluid may be circulated about said enclosure to dissipate heat therefrom.

10 Said source may be a cylindrical cathode having a number of ports therein, and an ionizable gas may be passed through said ports, said gas emanating from the ports impinging against shields to diffuse the gas over the surface of the cathode.

15 Said source may comprise a cathode of tantalum, said enclosure may contain a mixture of nitrogen and argon, and the heat of sputtering may be reflected back to said workpieces.

20 Preferably said workpieces are loaded into a carrier, the loaded carrier is moved relative to said enclosure to bring it into proximity therewith, said workpieces are moved serially into said enclosure, said path is circular, and said source is centrally located within said path.

25 The invention will now be described with reference to the accompanying drawings in which:

30 Fig. 1 is a perspective view of a tray or rack holding a pair of substrates to be sputtered;

35 Fig. 2 is a schematic plan view of an apparatus illustrating the flow of substrates from a loading-unloading position, to an outgas position, to a sputtering position and then back to the initial position;

40 Fig. 3 is an enlarged sectional view, taken along line 3—3 of Fig. 2, particularly illustrating the substrate batch loading facilities and the facilities for transferring the substrates into a sputtering chamber;

45 Fig. 4 is a sectional view of the sputtering chamber depicting a duct and shield arrangement for the introduction and diffusion of gasses into the chamber and a cooling system for controlling the sputtering chamber atmosphere;

50 Fig. 5 is a sectional view taken along line 5—5 of Fig. 4 illustrating the arrangement of diffusion shields and blocking shields that function to provide a uniform plasma and a uniform deposition of sputtered material on the substrates;

55 Fig. 6 is a partial sectional view through the cathode illustrating further details of the ducts, ports and the diffusion shields;

60 Fig. 7 is a partial sectional view of a gas diffusion plug which may be used instead of the shields shown in Fig. 6; and

Fig. 8 is a timing diagram showing the relative operation of the various component mechanisms.

65 In Fig. a tray 20 for receiving a pair of planar substrates 21 that may be constructed

of glass or other ceramic-like material is shown. The tray is formed of channel frame members 22 for supporting the edges of the substrates. Top and bottom cross members 23 and 24 are secured to the upright frames 22. Mounted on the bottom member 24 are a pair of wheels 26 and 27 which function to assist the support of the frame for movement during a sputtering operation. Offset from the plane of the wheels is a guide plate 28.

70 Prior to the sputtering onto the substrates, the substrates and trays are loaded in a magazine in a radial array and are pre-baked in an oven to outgas these elements. Referring to Fig. 2, the trays while mounted in a magazine 30 and still warm, are loaded into a magazine chamber 31. The magazine chamber 31 is one of three which are supported on a yoke 32 located within a housing 33 maintained at a vacuum condition approaching that existing in a sputtering chamber 34. During the loading operation at position 31A, the magazine chamber 31 is sealed from the housing 33 and exposed to permit the loading of the magazine of substrates. Following the loading of the substrates, the magazine chamber is evacuated down to vacuum conditions which exist within the housing 33. The yoke 32 is indexed 120° to move the magazine chamber into an outgas position 31B. The magazine chamber is held in this position for a period of time while the outgassing process continues to further extract any residual gasses within the trays 20 or the substrates 21. Next, the magazine chamber is moved to a transfer position 31C where the magazine 30 is rotated intermittently to move each tray into position to be advanced into the sputtering chamber 34. Following each advance of a tray into the sputtering chamber, a tray of completely sputtered substrates is moved into the vacated space in the magazine. The trays 20 are advanced in a circular path about a cylindrical cathode positioned within the sputtering chamber 34. The advance of the substrates is accomplished by a holder 36 which is successively indexed to move each tray from the load position about the cathode and back to the initial position where the trays are again transferred back to the magazine. The magazine chamber is subsequently returned to the initial load position 31A where air is introduced into the magazine chamber and the magazine of trays is unloaded and replaced with a magazine of heated trays of new substrates to be coated.

125 Attention is directed to Fig. 3 for consideration of the methods and apparatus for loading a magazine chamber 31 with a magazine 30 of substrates 21, advancing the magazine chambers through the outgassing position 31B and to the position 31C for

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transferring the substrates into the sputtering chamber 34. Each magazine chamber 31 comprises a tub-like chamber or drum 41 of stainless steel having a centrally disposed bearing block 42 secured to the bottom of the chamber. Mounted within the bearing block is a flanged shaft 43 on which is mounted a removeable magazine 30. The magazine comprises a plurality of radially extending U-shaped frames 44 having upright channels for receiving the trays 20. The shaft 43 has a shoulder 45 for supporting the magazines 30. The radial arrangement of the frames 44 locates the trays of substrates in substantially back to face relation. This arrangement together with the reflective inner surfaces of the stainless steel chamber 41 ensures the retention of the prebake heat in the substrates to provide for the further outgassing of the trays and the substrates. Slidably mounted within the shaft 43 is a lock rod 46. A drive flange 47 is secured to the lower end of the shaft 43 and has a plurality of circumferentially spaced bores 48 to receive drive studs 49 projecting from a hub 50 on a spline shaft 51 rotated by a solenoid controlled indexing drive unit 52. The lock rod 46 has a cross pin 53 extending through longitudinal slots formed in the shaft 43 and resting within an opposed pair of a group of lock slots 54 formed about the upper surface of the bearing block 42. The upper end of the rod 46 is engaged and urged downwardly by a compression spring 55. The upper section of the rod 46 has a tapered shoulder 59 which is engaged by a series of three radially disposed spring loaded lock plungers 56 (only one is shown), for locking the magazine to the shaft 43.

In the sputtering chamber transfer position 31C, an air cylinder 57 is operated to elevate the spline shaft and the hub 50 to move the studs 49 into the bores 48. When the hub 50 is elevated, a centrally located push pin 58 engages and pushes the lock rod 46 upwardly to move the cross pin 53 from the slots 54 thus freeing the shaft 43 for rotation. The tapered shoulder of rod 46 acts against the spring loaded plunger 56 to force the plunger into locking engagement with the magazine 30. The spline shaft 51 is incrementally rotated to rotate the hub 50, the flanged shaft 43 and the magazine 30 to index the frames 44 into position so that the trays 20 may be advanced into the chamber 34. When the indexing of the frames 44 is completed, the hub 50 is withdrawn and the cross pin 53 is again urged by spring 55 and positioned in a pair of slots 54 to lock the shaft 43 and the magazine channel frames 44 from movement while the magazine chamber 31 is moved to the unload position 31A.

The bottom of the magazine chamber 31

is also provided with a series of circumferential spaced apertures 61 which are indexed into position so that a pusher rod 62 may pass cyclically therethrough to advance each tray 20 into the sputtering chamber 34.

Considering the loading of a magazine 30 of substrates into the magazine chamber 31 at load position 31A, it will be noted that the magazine chamber has a band 66 girthing its midsection. This band rests on the edges of an arm 67 of the yoke 32. When a magazine chamber 31 is in the load position, a dished out plate 68 is advanced by an air cylinder 69 to engage the underside of the magazine chamber. The plate is provided with an O-ring seal 71, which engages the underside of the magazine chamber and seals the apertures 61 from the vacuum within the housing 33. The advance of the plate 68 moves the magazine chamber upwardly so that the top flange section engages a O-ring seal 72 mounted within a recess formed about a depending lip of an entry cylinder 73 that extends through an opening in the housing 33. The upper end of the cylinder 73 is sealed by a heavy metallic lid 74. With the magazine chamber 31 in its elevated position, air or a dry gas is introduced into a port 76 to normalize the pressure within the magazine chamber to that of the ambient atmosphere. The lid 74 is lifted and a pre-loaded magazine 30 of trays 20 is placed into magazine chamber. Upon completion of the loading operation, the lid 74 is replaced. Next, the air supply to the port 76 is interrupted and vacuum is drawn through the port 76. This vacuum may be initially established by a mechanical pump and then brought to a more finite value by use of a diffusion pump. When the vacuum is re-established in the magazine chamber 31, the plate 68 is lowered and the magazine chamber is again supported on the arm 67 of the yoke 32.

The yoke 32 is secured to a shaft 77 rotatably mounted with suitable seals and bearings in the lower section of the housing 33. The shaft 77 is driven by a bevel gear 78 which, in turn, receives motion from suitable solenoid controlled indexing unit (not shown) to index the shaft 77 and the yoke 32. The solenoid controlled drive belt unit is actuated following each complete loading of a magazine chamber 31 with a magazine of film-coated substrates and is effective to index the yoke through 120°. During each rotation of the shaft 77, a magazine chamber loaded with uncoated substrates is moved to the outgas position 31B (see Fig. 2). Inasmuch as there is a vacuum being continually maintained within the housing 33 and the temperature within the housing is hotter than the ambient atmosphere, the preheated substrates will

be further outgassed prior to loading into the sputtering chamber.

In Fig. 3, the yoke 32 indexes each magazine chamber 31 into position 31C to have the substrates moved into the sputtering chamber 34. Following advance of the magazine chamber 31, the air cylinder 57 is operated to advance the driving studs into the holes 48 formed in the driving plate 47. The solenoid controlled indexing unit 52 is actuated to rotate a belt 87 to cyclically impart motion to a sprocket 79 on the spline gear 51 which, in turn, rotates the spline gear 51, the hub 50, the flanged shaft 43 and the magazine 30 to index each tray 20 into an alignment with a slot 146 formed in the housing 33. As each tray is positioned in alignment with the slot 146, the push rod 62 with a roller 80 mounted thereon is advanced so that the roller engages the plate 28 of the tray. The push rod 62 is advanced by a commercially available ball-nut and screw arrangement 81 which is again driven by a solenoid controlled drive unit 82. The tray moves through the slot in the housing 33, along guides 83 and then between a pair of lateral supports or guide rails 84 until the top member 23 of the tray 20 is clipped by a pair of a group of spring clips 85 suspended from a top frame member 86 of the holder 36. The holder 36 includes a bottom frame member 89 (see Fig. 4) secured to a hub 91 attached to a drive shaft 92 which is cyclically indexed by suitable solenoid controlled driving unit 93. The bottom frame member 89 is electrically isolated from the remainder of the holder 36 by interposed insulator pillars 95 on which the main portions of the holder are supported.

When the pushrod 62 advances a tray 20 into the sputtering chamber 34, the roller 80 supports the tray on the plate 28. Actually the spring clips 85 are strong enough to hold the tray, but to ensure stability of the trays during the indexing through the sputtering chamber, the wheeled tray 20 moves on a rail 101 (see both Figs. 3 and 4). Upon indexing of the holder 36, the wheel 26 rides onto the rail 101 while the plate 28 rides on the roller 80. Following movement of the wheel 27 onto the rail 101, a tray of film-coated substrates is positioned to be supported on the roller 80.

Referring to Figs. 4 and 5, the sputtering chamber comprises an outer hollow cylinder 102 supported between a top plate 103 and a bottom plate 104, which is mounted on and sealed to the top of the housing 33. The cylinder 102 is constructed of aluminum and the inner surface is anodized to facilitate the absorption of heat. Wrapped around the outer periphery of the cylinder 102 are spiral convolutions of a tube or rod 106. A drum 107 is placed over the convolutions

so that a spiral passageway is defined between the convolutions and the outer surface of the cylinder 102 and the inner wall of the drum 107. Water is circulated through this spiral passageway to further aid in the dissipation of heat. Mounted within the cylinder 102, and secured to the top plate 103, is a second or inner coaxially positioned cylinder 108, also constructed of aluminum. This cylinder is provided with a circumferential duct 109 interconnecting ducts 111 and 112, which extend longitudinally away from the duct 109. Duct 109 is connected by way of tubing 113 to a source of inert gas or a mixture of inert gas and a reactive gas, such as a mixture of argon and nitrogen. The gas is distributed through the ducts and is emitted through a series of ports 114. The ports 114 are aligned with passageways 116 formed in a cylindrical cathode 117, constructed of tantalum or some other metal that is to be sputtered onto the substrates. Looking at Figs. 5 and 6, it will be noted that the passageways 116 are aligned with a series of strip shields 118 that extend longitudinally of the cathode and may be constructed of the same material as that of the cathode and electrically connected to the cathode so as to act as constituent parts of the cathode. Gas emanating from the ports 114 and the passageways 116 strikes the shields 118 and is diffused over the adjacent surfaces of the cathode 117.

In order to control the heat, the inside of the cylinder 108 is cooled by water. Water is admitted through a tube 121 and impinges in a well 122, then rises, and is exited out by exhaust tubing arrangement 123.

It will be noted that the cylinder 108 is provided with O-ring seals 131 and 132 to preclude the passage of water into the sputtering area. The outer cylinder 102 is also provided with O-ring seals 133 and 134 to preclude the entry of ambient atmosphere. Considering seals 131 as being typical, the top plate 103 is cut out to receive the upper section of the inner cylinder 108, which is also cut out. The cutout in cylinder 108 receives the seal 131 and the weight of the plate 103 acts to compress the seal. Water inside the cylinder 108 must pass contact lines of engagement 131a and b or lines 131c and d before the water can enter the sputtering area. In other words, the compression of the O-ring seals, both in the horizontal and vertical directions, provides two lines of contact that must be passed before a fluid can pass the seal.

Looking at Fig. 5, it will be noted that a tray of substrates 21, mounted between adjacent carrousel guide rails 84, is positioned between adjacent shields 118 during a sputtering operation. Due to the planar

construction of the substrate, the centre area of the substrate is closer to the cylindrical surface of the cathode and, hence, normally would receive a greater deposit of sputtered material. In order to compensate for this factor and enhance a uniform deposition of sputtered material, a pair of partially blocking shields 136 and 137 are positioned in the sputtering area to intercept the sputtered material at two locations during the time each substrate is in the sputtering chamber. The shield 136 is formed as a right-angle piece to preclude warping due to the heat generated by the sputtering operation. The shielding effect provided by shield 136 is such that the edge sections of the substrates 21 are fully exposed to the normal sputtering action. It should be noted also that the strip shields 118 project towards the same edge sections and inasmuch as these shields can act as part of the cathode, there is an increased amount of material sputtered onto the edge sections. The overall effect is that the sputtered material is uniformly deposited on the substrates exiting from the sputtering chamber.

When the holder 36 advances in a circular path about the coaxially located cathode and a film coated substrate is moved into alignment with the exit slot, an upper pushrod 141 is operated by a mechanism 142, similar to the mechanism used to advance the pushrod 62, so as to push the tray 20 downwardly from the spring clips 85 against the still elevated pushrod 62. The pushrods 141 and 62 now move in unison to move the tray back into the magazine 30. When the magazine 30 is completely loaded with film-coated substrates, the solenoid controlled indexing mechanism for the yoke 33 is again operated to advance the magazine chamber 31 back to the original position 31A. Following admission of air into the magazine chamber 31, the lid 74 is lifted and the magazine of trays of film-coated substrates may be removed and a magazine of trays of uncoated substrates loaded into the magazine chamber.

The operation of the various solenoid controlled drive units and the air cylinders may be sequentially controlled by a cam-operated controller in the sequence depicted in timing diagram of Fig. 8. Alternatively the operation of the various component mechanisms may be controlled by a series of limit switches and an electrical control circuit. The particular means of sequence control may take other forms so long as the various handling and process steps are accomplished in the sequence described.

Referring to Fig. 7, there is shown an alternative arrangement for diffusing the inert gas over the cathode. The shields 118 are replaced by a series of plugs 151 seated

within openings 116 in the cathode 117. The plugs each have a blind bore 152 and a pair of slots 153 exposing the bore to the gas emanating from the aligned port 114. It will be noted that the seated end of the plug is exposed to the relatively cool inner cylinder 108. The projecting plugs act as part of the cathode and are positioned closer to the edges of the substrates between indexing of the holder 36 so as to ensure a more uniform deposition of metal on the substrate.

At load position 31A, with the lid 74 removed, a prebaked magazine 30 (Figs. 2 and 3) of still warm trays of substrates 21 is loaded in the magazine chamber 31. When the magazine chamber 31 is loaded, the lid 74 is replaced and vacuum drawn through the port 76. The elevator plate 68 is lowered to move the magazine chamber back onto the yoke 32. Yoke 32 is then indexed to the outgas position 31B and held there while one of the other magazine chambers 31 is being unloaded and loaded and the other magazine chamber is being utilized to supply and receive substrates to and from the sputtering chamber 34. Upon the next advance of the yoke 33, the outgassed magazine of substrates is positioned for loading into the sputtering chamber 34. The hub 50 and flange 47 coupling is established by actuation of air cylinder 57 so that the magazine 30 may be subsequently indexed. The pushrod 62 is actuated to advance the first aligned tray through aligned slots 146 and 147 formed in the top of the housing 33 and the bottom plate 104 of the sputtering chamber into the holder 36. These aligned slots are substantially tangent to the circular path of movement of the trays in the sputtering chamber. The holder 36 is then indexed and the loaded tray is moved so that the wheels 26 and 27 ride onto the rail 101. The trays 20 are held by the spring clips 85, and wheels 26 and 27 riding on the rail 101 ensure stable positioning of the substrates during the sputtering operation. High voltage is applied through connector 151 while the inner cylinder 108 and the holder 36 are maintained at ground potential.

The holder 36 is indexed to move the trays 20 in a circular path about the coaxially located cathode 117. The cathode strip shields 118 together with the blocking shields 136 and 137 cooperate to ensure that the edges of the substrates 20 receive deposited metal in the same amounts as is deposited on the centre sections of the substrates.

The movement of the holder 36 positions a coated tray of substrates over the aligned slots 146 and 147 so that the plate 28 rides on the roller 80 of the still elevated pushrod 62. The pushrods 141 and 62 now

work in unison to lower the tray 20 into the magazine 30. The magazine 30 is indexed one position by movement transmitted through the now engaged coupling provided by lugs 49 on hub 50 engaging within the holes 48 formed in flange 47. This cyclic operation continues until the magazine 30 is fully loaded with coated substrates. Next, the yoke 33 is again moved to position the magazine chamber beneath the lid 74 for subsequent unloading and reloading of magazines.

When the apparatus is used to deposit a film of beta tantalum, the gas introduced into the sputtering chamber is argon. If the beta tantalum film is to be used for the fabrication of an oxide dielectric of a capacitor, then a relatively thick film e.g., 5000Å must be deposited at a slower rate. This is easily accomplished by the present machine by merely slowing down the rate of indexing of the various component mechanisms. When the deposit is to be a film of tantalum nitride for subsequent fabrication of resistor elements, the gas introduced into the sputtering chamber is a mixture of argon and nitrogen. In this instance, it is necessary to maintain heat in the substrates so as to produce resistors with a low temperature coefficient of resistance. This heating may be accomplished by mounting a thin reflective sheet of stainless steel behind each substrate mounted in a holder 20.

Variations will occur to those skilled in the art. For example, the component units may be rearranged so that the yoke 32 advances the magazine chambers 31 relative to the top of the sputtering chamber 34 rather than the bottom of the chamber. In this instance, the mechanisms will be reversed, and the trays will be pushed down instead of up to load the carrousel holder 36.

#### WHAT WE CLAIM IS:—

1. A method of coating workpieces wherein an enclosure containing a source of coating material is maintained at a controlled atmosphere different from the ambient atmosphere, a plurality of workpieces each having a planar surface are entered into said enclosure substantially without disruption of said controlled atmosphere, said workpieces are advanced along a closed path about said source and are coated, the cen-

tral portion of each of said surfaces being shielded from said source of coating material for part of the time during which coating occurs, and said workpieces are subsequently removed from said enclosure substantially without disruption of said controlled atmosphere.

2. A method as claimed in claim 1 wherein said coating material is sputtered onto said workpieces.

3. A method as claimed in claim 2 wherein said source includes a cathode dimensioned and arranged such as to provide a substantially uniform coating on said planar surface.

4. A method as claimed in claim 2 or 3 wherein said source is a cylindrical, hollow cathode, cooling fluid is circulated within said cathode to dissipate heat therefrom, and cooling fluid is circulated about said enclosure to dissipate heat therefrom.

5. A method as claimed in claim 2, 3 or 4 wherein said source is a cylindrical cathode having a number of ports therein, and an ionizable gas is passed through said ports, said gas emanating from the ports impinging against shields to diffuse the gas over the surface of the cathode.

6. A method as claimed in claim 2, 3, 4 or 5 wherein said source comprises a cathode of tantalum, said enclosure contains a mixture of nitrogen and argon, and the heat of sputtering is reflected back to said workpieces.

7. A method as claimed in any preceding claim wherein said workpieces are loaded into a carrier, the loaded carrier is moved relative to said enclosure to bring it into proximity therewith, said workpieces are moved serially into said enclosure, said path is circular, and said source is centrally located within said path.

8. A method of coating workpieces substantially as herein described with reference to the accompanying drawings.

9. A workpiece coated by a method as claimed in any preceding claim.

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1. A method of coating workpieces wherein an enclosure containing a source of coating material is maintained at a controlled atmosphere different from the ambient atmosphere, a plurality of workpieces each having a planar surface are entered into said enclosure substantially without disruption of said controlled atmosphere, said workpieces are advanced along a closed path about said source and are coated, the cen-

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