

[54] **DEPOSITING MATERIAL ON A SUBSTRATE USING A SHIELD**

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[22] Filed: **May 31, 1974**

[21] Appl. No.: **475,007**

[52] U.S. Cl. **204/192; 117/93; 117/107.1; 118/49.1; 118/49.5; 118/50.1; 118/624; 204/298**

[51] Int. Cl.²..... **C23C 15/00; C23C 13/02**

[58] Field of Search..... **204/192, 298**

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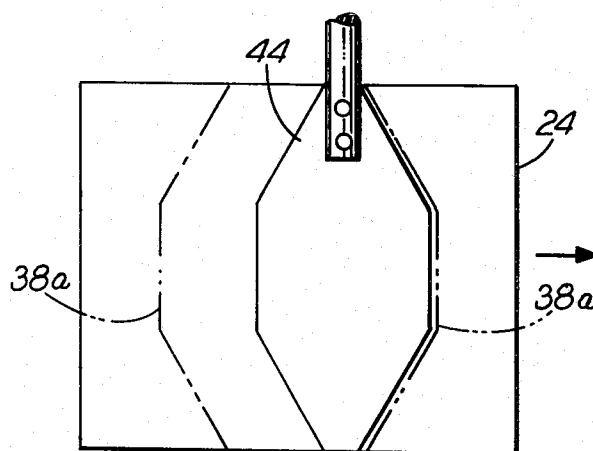
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[57] **ABSTRACT**

The uniformity of the thickness of material, deposited on a substrate by ion bombardment of a cathode, i.e., by sputtering, is improved by shielding. A shield is shaped to conform with plots of lines of constant thickness of the material deposited by a sputtering machine. The shield is inserted between the cathode and substrate during a preselected interval of the sputtering time to shade a portion of the substrate and prevent excess deposition of material thereon. Where characteristics of the sputtering machine are such that deposition must be reduced in a wide swath along the length of the substrate, a variable area shield is used.

10 Claims, 19 Drawing Figures



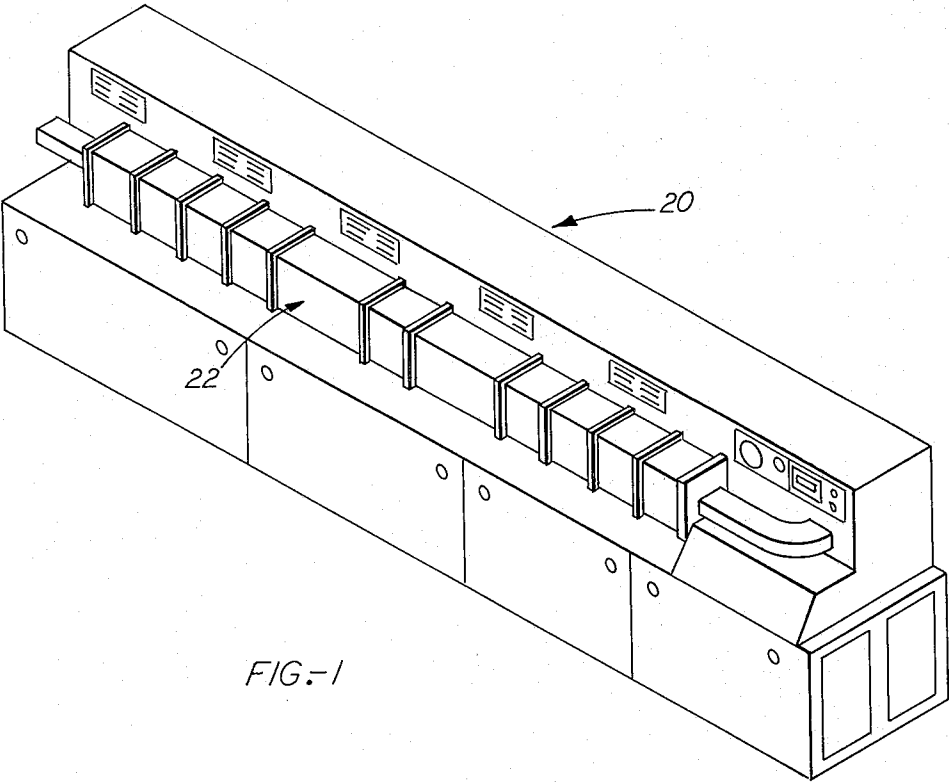


FIG-1

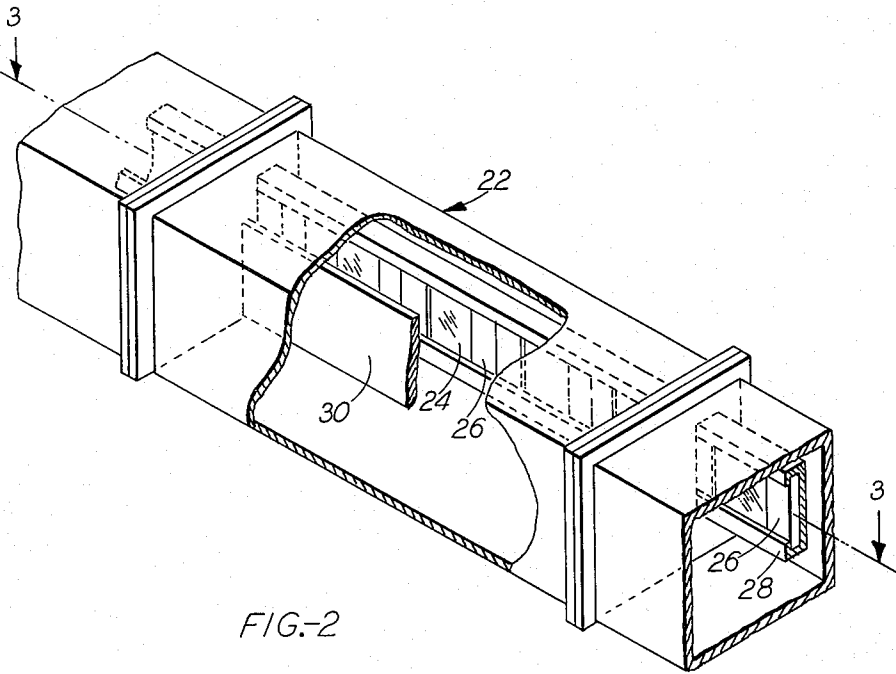


FIG-2

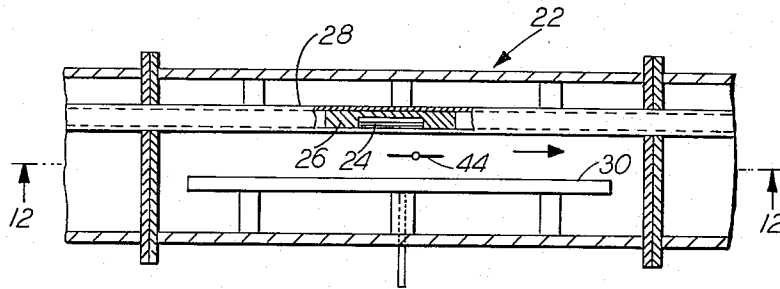


FIG-3

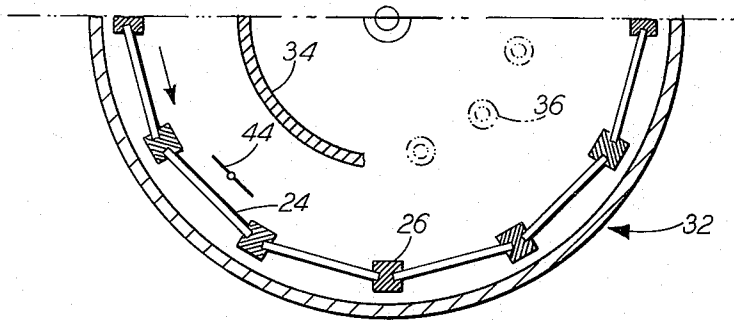


FIG-4

FIG-5

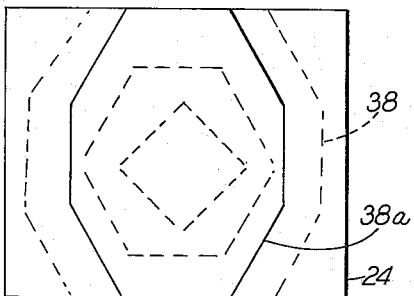


FIG-6

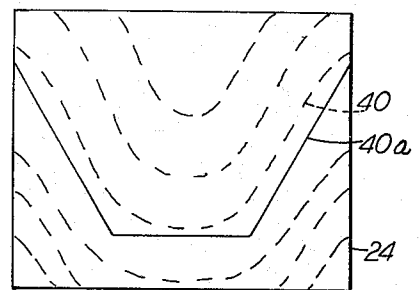


FIG-7

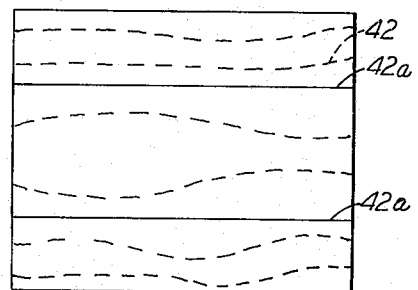


FIG-8

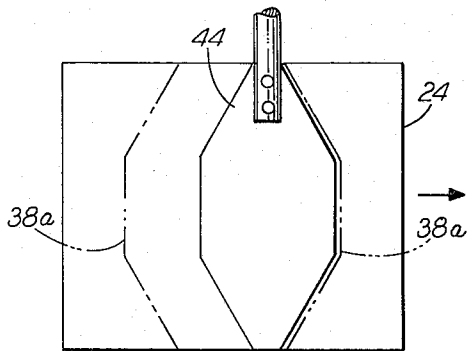


FIG-9

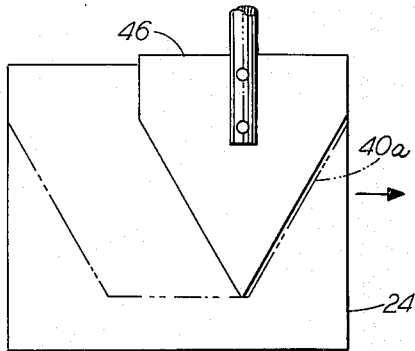


FIG-10

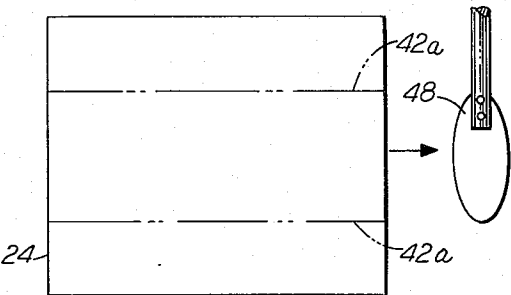


FIG-11

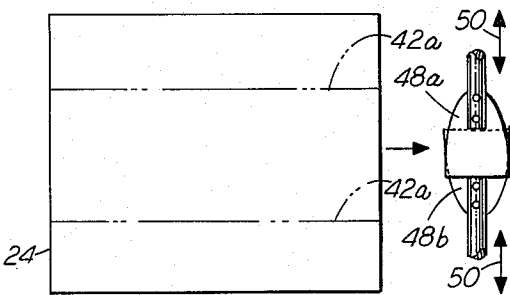


FIG-11a

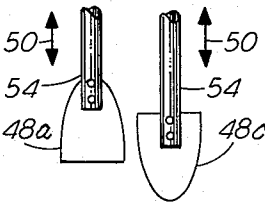
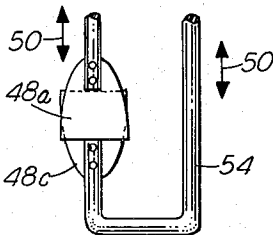


FIG-11b



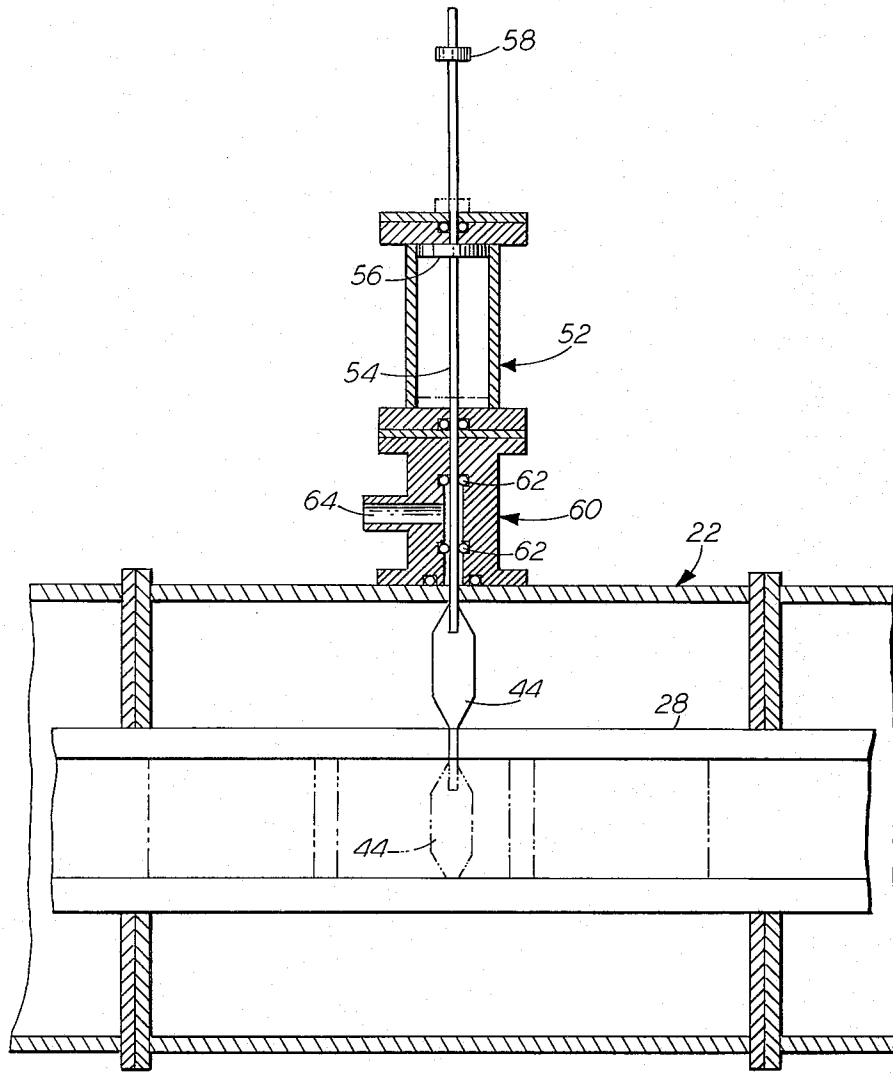


FIG. 12

FIG-13

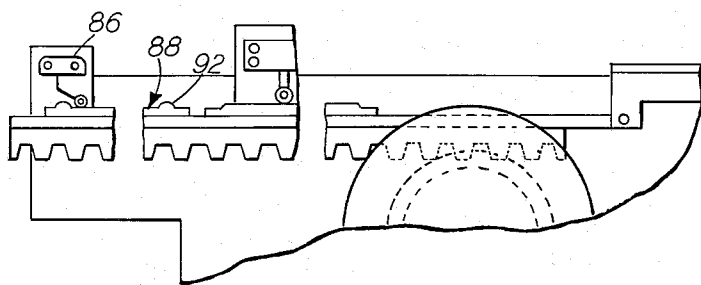
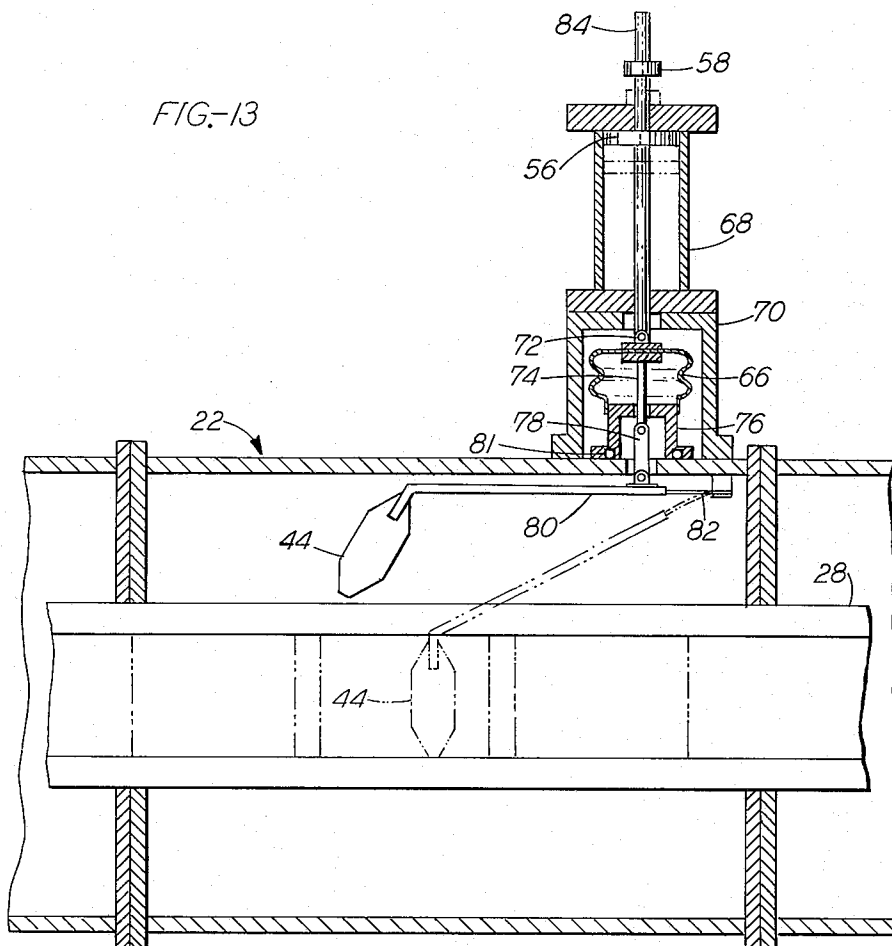


FIG-15

FIG-16

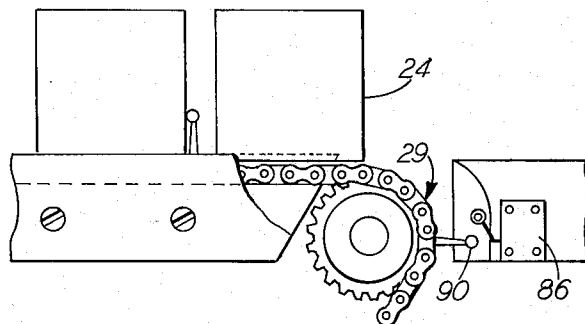
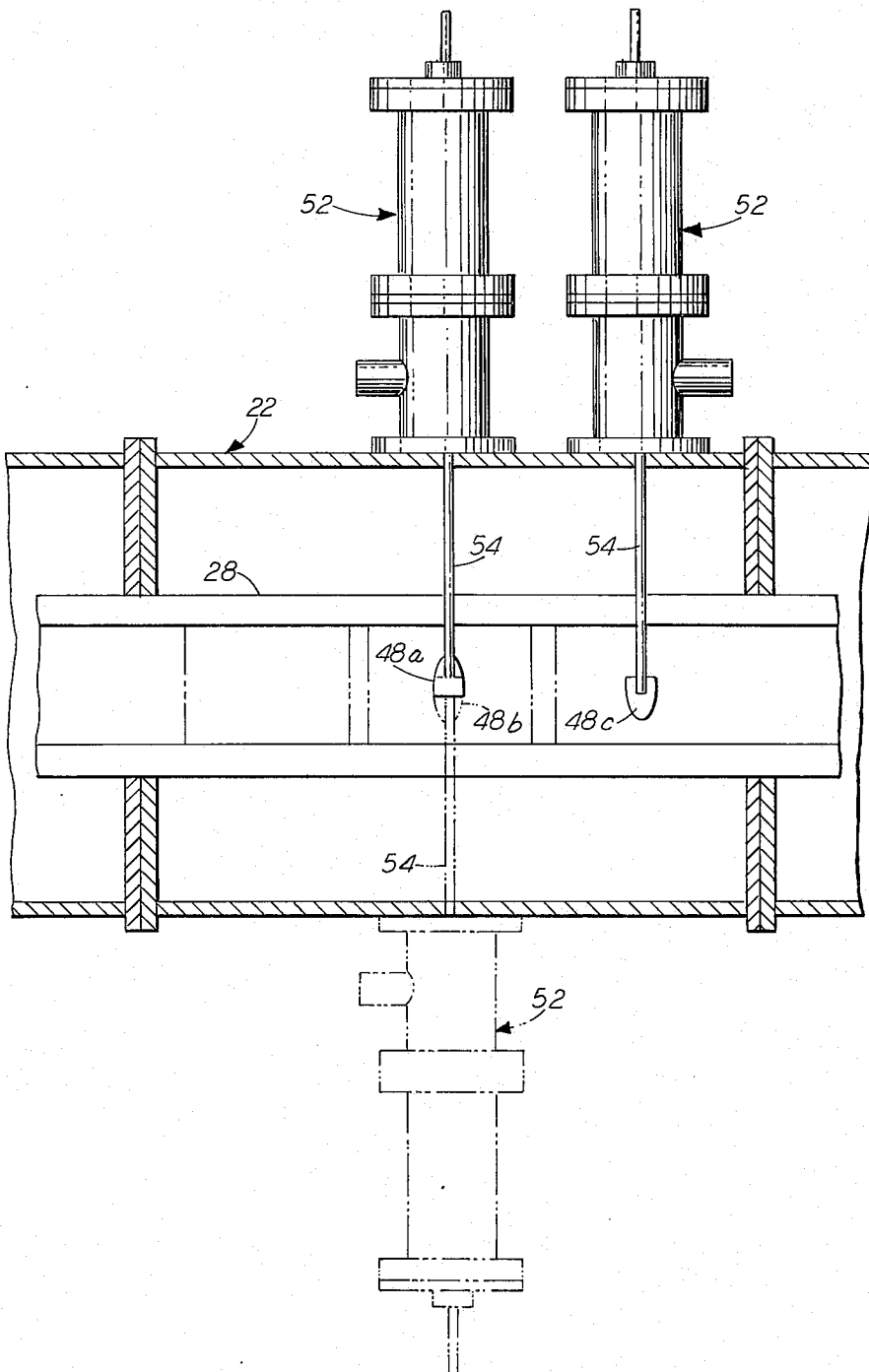


FIG-14



DEPOSITING MATERIAL ON A SUBSTRATE USING A SHIELD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to improved methods and apparatus for depositing material on a substrate. More particularly, it relates to shading portions of a substrate with a shield which may be inserted and removed during the deposition of a thin film of material to make the thickness of the deposited material more uniform over the substrate.

2. Description of the Prior Art

In the manufacture of semiconductor apparatus, thin films are deposited on ceramic or glass substrates and various devices formed therefrom. For example, a film of resistive material may be deposited on a substrate and "thin-film" resistors formed; or conductive material may be deposited and conductive paths formed; or both materials may be deposited and resistors and interconnecting conductors formed to produce a thin-film electrical circuit.

One method used for depositing material on the substrate, especially high melting-point materials such as tantalum, is ion bombardment, i.e., sputtering, of the material in close proximity to the substrate. The process may be carried out in bell jar, in-line, or rotary types of sputtering chambers. Information relative to carrying out the process may be had from two excellent sources: R. W. Berry, P. M. Hall and M. T. Harris, *Thin Film Technology*, D. VanNostrand Company, Inc., Princeton, New Jersey, (1968); and L. J. Maissel and R. Glang, *Handbook of Thin Film Technology*, McGraw-Hill Book Co., New York, N. Y. (1970). Information relative to sputtering apparatus may be had from U.S. patents: Charschan et al. 3,294,670; and Kauffman et al. 3,521,765, both assigned to the assignee of record.

In the sputtering process, many factors, which involve the particular apparatus being used, determine the distribution of material over the surface of the substrate. That is, the thickness varies somewhat in a pattern or contour peculiar to the apparatus and configuration used. Typically, variations are from about $\pm 4\%$ to about $\pm 10\%$ and about $\pm 6\%$ is a common experience.

As a result of the variations in the film thickness, the characteristics of the devices, such as resistors made from the material on the substrate by photolithographic processes must be adjusted, usually by anodizing, to compensate for the variations. The time required for anodizing may be substantially shortened by depositing the material with a more uniform thickness initially.

As noted, the thickness varies along contours peculiar to the particular apparatus and deposition conditions. Consequently, in order to make the thickness more uniform, the deposition must be reduced, within the contours where the material would be thicker (generally the center portions of the substrate), to the extent that it is nearly the same as elsewhere on the substrate.

Some prior art apparatus (such as that disclosed in copending application of C. H. George, Ser. No. 175,247, filed Aug. 26, 1971, now U.S. Pat. No. 3,856,654 and assigned to the assignee of record) has been able to improve uniformity by means of a fixed shield in the sputtering chamber. However, a fixed shield cannot be adjusted and, therefore is limited in its

ability to compensate when sputtering conditions change. In other prior art cases, moving shields or controllable shields have been used to produce thin films which increase in thickness at an approximately uniform rate, or to prevent deposition until sputtering conditions reach equilibrium conditions, i.e., stabilize sufficiently so that deposition can proceed at the planned rate. But these shields are not capable of producing a film of uniform thickness or improving the uniformity of deposition.

What is needed is a shield which approximates the contour of the area which would be overdeposited and which can be positioned to shade that area of the substrate for just the necessary time to prevent overdepositing. It is also desirable that the area of the shield be capable of being increased or decreased to accommodate changing conditions.

SUMMARY OF THE INVENTION

Accordingly, an object of the invention resides in providing new and improved methods and apparatus for depositing material on a substrate. With this and other objects in view, the present invention contemplates a new and improved method for depositing material on a substrate which includes inserting a shield between the cathode and the substrate during ion bombardment of the cathode in a sputtering chamber to deposit the material. The shield shades selected portions of the substrate and is withdrawn after a predetermined interval so that the uniformity of the material on the substrate is increased.

The present invention also contemplates a new and improved apparatus of the kind wherein a cathode acts as a source of material and is bombarded with ions to deposit the material on a substrate. Mechanisms external to a sputtering chamber position a shield between the cathode and substrate inside the chamber during selected intervals of bombardment of the cathode to shade selected portions of the substrate and reduce any variation in thickness of material deposited over the surface of the substrate.

The thickness of material deposited during ion bombardment varies over a substrate and is dependent on many factors indigenous to the particular apparatus and sputtering process. However, the variations are consistent and the thickness of the material on a representative sample of substrates may be measured and contours of constant thickness plotted. A shield of the general shape of the contours is inserted between the cathode and the substrate just long enough to reduce the thickness of what would be an overdeposited area, usually the center of the substrate, to that of the surrounding area.

In some instances the factors influencing deposition cause a swath of thicker material to be deposited along the centerline of the substrate and, therefore, an adjustable shield is inserted between the cathode and substrate which is adjusted to the width of the swath. The width depends on the material and sputtering conditions.

The invention further contemplates mechanisms which position shields from outside the chamber either through sliding type vacuum seals or hermetic seals.

DESCRIPTION OF THE DRAWINGS

Other objects and features of the invention will be more readily understood from the following detailed

description of the specific embodiment thereof, when read in conjunction with the accompanying drawings in which:

FIG. 1 is an isometric view of an "in-line" sputtering machine showing an "in-line" sputtering chamber;

FIG. 2 is an isometric view of the "in-line" sputtering chamber of FIG. 1;

FIG. 3 is a plan view along line 3—3 of the chamber of FIG. 2 showing the interior of the chamber;

FIG. 4 is a partial cross section showing the interior of a "rotary" sputtering chamber;

FIG. 5 is an illustration of topographical contours of constant thickness of material deposited on a substrate in an "open-end in-line" type apparatus;

FIG. 6 is an illustration of topographical contours of constant thickness of material deposited on a substrate in a "closed-end in-line" prior art type apparatus;

FIG. 7 is an illustration of topographical thickness contours of material deposited in "closed-end in-line" apparatus, the contours of which are illustrated in FIG. 6, using rod cathodes and a.c. sputtering;

FIG. 8 is an elevation showing the shape of a shield for the topography of FIG. 5;

FIG. 9 is an elevation showing the shape of a shield for the topography of FIG. 6;

FIG. 10 is an elevation showing the shape of a shield for the topography of FIG. 7;

FIG. 11 is an elevation showing a variable-area shield for the topography of FIG. 7;

FIG. 11a is an elevation showing an alternate arrangement for the shield portion of FIG. 11;

FIG. 11b is an elevation showing another arrangement for the shield portion of FIG. 11;

FIG. 12 is a cross sectional elevation of a pneumatic cylinder and an evacuated seal arrangement for operating the shield of FIGS. 8 and 9;

FIG. 13 is a cross sectional elevation of a pneumatic cylinder and bellows arrangement for operating the shields of FIGS. 8 and 9;

FIG. 14 is a partial cross sectional elevation of a pneumatic cylinder arrangement for operating the shield of FIGS. 11 and 11a or 11b;

FIG. 15 is a partial elevation showing a limit switch and cam for coordinating the operation of a shield with the "open-end, in-line" type sputtering apparatus;

FIG. 16 is a partial elevation showing the mounting of a limit switch to coordinate the operation of a shield with the "closed-end, in-line" type apparatus; and

FIG. 17 is a diagram of an electrical circuit for controlling the operation of the shields in conjunction with a limit switch.

DETAILED DESCRIPTION OF THE INVENTION

Apparatus for Depositing Material

Referring now to FIG. 1, there is shown an "open-end, in-line" sputtering machine 20 of the type having a sputtering chamber 22 and disclosed in U.S. Pat. No. 3,294,670 which issued to S. S. Charschan et al. Dec. 27, 1966. Another apparatus having a similar sputtering chamber 22, a "closed-end, in-line" sputtering machine is disclosed by U.S. Pat. No. 3,521,765 which issued to R. D. Kauffman et al. July 28, 1970. The subject matter of the U.S. Pat. Nos. 3,294,670 and 3,521,765 patents is incorporated herein by reference.

Substrates 24 on which material is to be deposited (refer to FIG. 2) may be transported through the chamber 22 in carriers 26 which are pushed along a track 28.

The motion of the carriers 26 may be nearly constant or there may be a pause as carriers are added to and removed from the column of carriers being pushed through the chamber 22. In other cases, the substrates 24 may be carried through the chamber 22 by a chain conveyer 29 (refer to FIG. 16) in the bottom of the track 28 rather than a column of the carriers 26. The conveyer 29 usually operates at a constant speed.

In addition to apparatus which transports the substrates 24 through the chamber 22 in a straight line, such as sputtering machine 20, there are other types which transport the substrates in steps in a circular path around a cylindrical sputtering chamber 32 (refer to FIG. 4). Such apparatus is described in the aforementioned copending C. H. George application.

Referring now to FIG. 3, which is a plan view along line 3—3 of FIG. 2 looking down into the chamber 22, the track 28 is partially cut away to show the carrier 26 transporting one of the substrates 24 from left to right past a cathode 30.

In a rotary version of the sputtering chamber (refer to the partial cross-section FIG. 4) the substrates 24 are carried counter-clockwise around the chamber 32 past either a cylindrical cathode 34 or rod cathodes 36 (shown in phantom) which are easy to cool.

As disclosed in the various reference cited, the cathodes 30, 34 and 36 are highly negative with respect to the chambers 22 and 32 and substrates 24; and an inert gas, such as argon, is maintained at less than atmospheric pressure in the chambers. However, the cathodes 30, 34 and 36 may be operated with an a.c. potential so that they are alternately highly positive and then highly negative with respect to the chambers 22 and 32. In either case, the gas is ionized, the cathodes 30, 34 and 36 are bombarded by the ions, particles of cathode material are dislodged, and the particles are deposited on the substrate 24. Thus, the cathodes 30, 34 and 36 must be composed of the material to be deposited on the substrates 24.

The transfer of material from the cathodes to the substrates 24 is a result of particle collisions and influenced by many factors which depend on the sputtering machine 20 and process conditions. These give rise to variations in the thickness of the material across the substrates 24. However, the variations are essentially the same for each of the substrates 24 once the sputtering conditions have been established.

Uniformity of the Deposited Material

The thickness of the material deposited on the substrates 24 may be measured in a number of ways; but where a resistive material, such as tantalum or tantalum nitride, is deposited, a four-point probe resistance measurement in ohms per square may be made. The resistance of the material deposited on the substrates 24 is measured at regular intervals over the area of the substrates. Although the resistance in ohms per square may be converted to thickness in angstroms or other linear measure it is usually more convenient to leave it in the form of ohms per square. Measurement of a representative sample of substrates permits plotting the general topographical contours (in terms of ohms per square) of the material deposited on the substrate.

For example, FIG. 5 is representative of the distribution of tantalum material deposited on substrates 24 by the "open-end, in-line" type apparatus which transports the substrates 24 through the sputtering chamber

in the carriers 26. Here the topographical contours 38 of constant thickness have roughly an octagon shape and the material on the substrates 24 within the solid contour 38a is thicker than the material outside the contour. The variation between the thickest, midrange, and thinnest portions of the sputtered layer is approximately $\pm 6\%$. By shielding the area within the contour 38a for a portion of the sputtering time, using applicant's invention for shading or shielding the substrates 24, the variation may be reduced to about $\pm 3\%$.

Another example, refer to FIG. 6, is representative of the distribution of tantalum material deposited on a substrate 24 by the "closed-end, in-line" type apparatus which transports the substrates 24 through the sputtering chamber 22 and on a conveyor 29 rather than the carriers 26. Here contours 40 of constant thickness are truncated and the material within (above) the solid contour 40a is thicker than the material outside (below) the contour 40a. The variation in this case is about $\pm 4.5\%$ of the midrange thickness. By shading or shielding the area within the contour 40a for a portion of the sputtering time in accordance with applicant's invention, the variation may be reduced to about $\pm 3\%$.

In the "closed-end, in-line" apparatus, the plate cathode 30, refer to FIG. 3, may be replaced by a cathode (not shown) constructed of horizontal rods and the sputtering performed with alternating current. Under these conditions, topographical contours 42, refer to FIG. 7, are obtained wherein the material deposited along a horizontal centerline is thicker than elsewhere. Thus, a swath of material between the solid contours 42a is thicker than the material between the contours and the edges of the substrates 24. The variation here may be as much as $\pm 10\%$ of midrange and this may be reduced to about half by use of applicant's invention.

Shading or Shielding the Substrate

Referring again to FIGS. 3 and 4, a shield 44 is placed between the substrate 24 and cathodes 30, 34 or 36 depending on which apparatus and type of cathode is used. Typically, the shield is positioned approximately 1 inch away from the substrate 24.

The shape of the shield 44 is chosen with due regard to the movement, or lack thereof, of the substrates 24 through the sputtering chamber 22. Referring now to FIG. 8, the contour 38a of FIG. 5 is shown in phantom. The shield 44 is made narrower than the contour 38a because the substrates 24 move through the sputtering chamber 22 in the direction of the arrow. The shield 44 is interposed between the cathode 30 and one of the substrates 24 when what would be the right-hand edge of the contour 38a is in line with the right-hand edge of the shield, and the shield is removed when that one of the substrates 24 has moved to the point where what would be the left-hand edge of the contour is in line with the left-hand edge of the shield.

Similarly, referring to FIG. 9, the contour 40a is shown in phantom and a triangular shield 46 for this contour is shown narrower than the area to be shielded because of the movement of substrates 24 in the direction of the arrow.

Where the area to be shaded is a swath (refer to FIG. 10) between the contours 42a (shown in phantom), a roughly oval-shaped shield 48 may be used. This shield is aligned with the swath to be shaded. Since the swath would be thickest at the center and fall off toward the

edges, the shield 48 is made wider at the center to provide more shading there.

In order to avoid having to make another shield 48 when the width of the swath between contours 42a changes because of changes made in the process and/or equipment, the shield 48 may be made in two overlapping portions 48a and 48b (refer to FIG. 11) such that the portions 48a and 48b may be moved in the directions of the arrows 50 to increase or decrease the width of the swath which is shaded. In essence this is a shield which may be varied in area or size. However, the portions 48a and 48b are operated from opposite sides of the sputtering chamber 22. Alternatives, in which the portions may be operated from the same side of the chamber 22, are shown for a side-by-side arrangement in FIG. 11a and with an offset piston rod in an overlapping arrangement in FIG. 11b. The shield portions 48a and 48c are moved from the same side of the sputtering chamber 22 in the direction of the arrows 50 to change the width of the area shaded.

Referring now to FIG. 12, which is a view of the sputtering chamber 22 along the line 12—12 of FIG. 3, the shield 44 may be positioned between the substrates 24 and the cathode 30 by a pneumatic cylinder 52. A piston rod 54 is moved by a piston 56, fixed thereto, when air is admitted to the cylinder. The distance the rod 54 moves and, therefore, the distance the shield 44 is inserted into the chamber 22, is determined by the position of a split collar 58 on the rod 54. The collar 58 is positioned on the rod 54 and clamped by a screw (not shown) so that, when the collar strikes the end of the cylinder 52, the shield 44 will be in the desired position. The piston 56 itself acts as the stop for the retracted position.

The chamber 22 is at a pressure below atmospheric. In order to keep ambient air or any gas leaking past the seals of the cylinder 52 from entering the chamber 22, an evacuated seal 60 is interposed between the cylinder and the chamber. The seal 60 includes O-ring seals 62 above and below a vacuum port 64. A pressure, slightly below the pressure of chamber 22, is maintained at the port 64 to evacuate the seal 60 and prevent leakage of gas into the chamber.

The mechanism of FIG. 12 is a simple and directly operating one. However, it has seals which will wear, require continuous application of a vacuum, and must be replaced occasionally. This may be avoided by the bellows mechanism shown schematically in FIG. 13 which is an elevation of the interior of the sputtering chamber 22. A flexible bellows 66 seals the chamber 22 from the outside atmosphere. A pneumatic cylinder 68 is supported on a bridge 70 and connected to a yoke 72 which is fastened externally to the bellows 66. Internally a stem 74, guided in a cylindrical support 76, connects the bellows 66, through a link 78 to a support arm 80 for the shield 44. An O-ring 81 provides a seal between the support 76 and the chamber 22 so that, together, the bellows 66, support 76 and O-ring 81 seal the chamber 22 from the atmosphere. The arm 80 is hinged to the inside of the chamber 22 by means of a leaf spring 82. In order to reduce the length of the stroke and, therefore, the amount of flexing the bellows 66 must do, the length of the arm 80 from the link 78 to the shield 44 is made much greater than from the link 78 to the end of the spring 82 which is fastened to the chamber 22. As in the direct acting cylinder 52, a stop 58 is clamped on an extension 84 of the piston rod

to permit adjusting the distance the shield 44 is inserted into the chamber 22 (as shown in phantom) and the piston 56 acts as the stop for the retracted position.

Although pneumatic cylinders 52 and 68 were chosen to illustrate operation of the shield 44 in FIGS. 12 and 13 respectively, other means of operation may be used. For example, in the direct acting apparatus of FIG. 12, the pneumatic cylinder may be replaced by a linear electric motor. Or, in the case of the short-stroke, bellows mechanism of FIG. 13, the pneumatic cylinder 68 may be replaced by a single revolution motor and adjustable-stroke, crank mechanism arranged to lower the shield 44 on one revolution and raise it on the next revolution.

Again, using pneumatic cylinders to illustrate (refer to FIG. 14) the shield portions 48a and 48b of FIG. 11 may be positioned from opposite sides of the chamber 22 by two pneumatic cylinders 52, one of which is shown in phantom on the opposite side of the chamber, or the shield portions 48a and 48c may be positioned from the same side of the chamber by means of the side-by-side pneumatic cylinders 52 in either the side-by-side arrangement of FIG. 11a or the overlapping arrangement using the offset piston rod 54 of FIG. 11b.

Operation of the Shields

The shields, such as shield 44, are inserted between cathodes and substrates to shade predetermined portions of the substrates for predetermined periods of time. This requires coordinating the insertion of any of the shields with the movement of the substrate 24 and timing the duration of the shielding. This may be done by means of a limit switch 86 and cam 88 (refer to FIG. 15) for the "open-end, in-line" type apparatus; or by means of the limit switch 86 (refer to FIG. 16) mounted to engage lug 90 for the "closed-end, in-line" type apparatus.

Once the insertion of a shield, such as shield 44, has been coordinated with the movement of the substrates 24 through the sputtering apparatus by the limit switch 86, actuation of solenoid valves to operate pneumatic cylinders, or relays to operate electric motors, or the equivalent of these, may be achieved through the control circuit of FIG. 17.

When the limit switch 86, refer now to FIG. 17, is moved to its normally open position and allowed to close again; for example, by one of the cam lobes 92 on cam 88 (refer to FIG. 15) or by the lug 90 (refer to FIG. 16), the coil of a relay 94 is energized and its normally open contact 96 is closed. The closed contact 96 applies energy to the relay 94 through a normally closed contact 98 of a timer 100. Thus, the relay 94 will remain energized until contact 98 is opened after a preset time delay to open (TDO). The timer 100 preferably should have a range of from 0.1 to about 400 secs.

When relay 94 is energized, it also closes a normally open contact 102, which energizes a clutch 104 of a delay timer 106, preferably having a range of 0.1 to 400 secs., and starts timing a delay, which is preset on the timer 106, after which the shield is inserted. At the end of its delay period, timer 106 opens a normally closed contact 108 to de-energize a drive motor 110 and closes normally open contact 112 to energize a clutch 114 of timer 100. The timer 100 starts timing the duration of shielding, which has been preset on that timer, and immediately closes normally open contact 116 to

energize a spring-return solenoid valve 118 through a normally closed contact 120.

Referring now to FIG. 12 for illustration, the closed contact 116 and energized solenoid 118 actuate the pneumatic cylinder 52 so that it inserts the shield 44 between the cathode (not shown) and one of the substrates 24 in the chamber 22. At the end of the preset time, the timer 100 momentarily opens a normally closed contact 120, to de-energize a timer motor 122; opens the contact 116 to de-energize the solenoid valve 118 so that the spring returns the valve and the cylinder 52 withdraws the shield 44 from between the cathode and substrate in the chamber 22; and momentarily opens the contact 98 to de-energize the relay 94 and reset the circuit. The shield 44 may also be manually operated independently of the timers 100 and 106 by operation of the switch 124. This is helpful for initial set up and positioning.

Applicant's method and apparatus provides distinct advantages over the prior art in increased uniformity of the deposited material by shielding the substrate for only a portion of the deposition time. Further advantage and improved uniformity is achieved by shaping the shield to thickness contours and shielding only predetermined portions of the substrate. Still further advantage is gained, in certain cases, by making the shield variable in size.

While there has been described and illustrated herein practical embodiments of the present invention, it is to be understood that various modifications and refinements, which may depart from the disclosed embodiment, may be adopted without departing from the spirit and scope of the invention. For example, shields, such as the shield 44, may be perforated or slotted, particularly adjacent the periphery, soften the shading and improve the thickness uniformity in specific instances. As another example, if the shields are actuated by a linear motor or similar magnetic device, the motor or device may be enclosed by the chamber 22 to eliminate the need for the evacuated seal 60.

What is claimed is:

1. An improved method for depositing material on a substrate wherein a cathode acts as a source of material, and wherein a layer of material is deposited on the substrate by ion bombardment of the cathode in a chamber; wherein the improvement comprises:

inserting a shield between the cathode and the substrate to selectively shade portions of the substrate from the material being deposited thereon, the configuration of the shield being determined by the variations in the deposit thickness which would occur in the absence of said shield; and withdrawing the shield after a predetermined interval, to increase the uniformity of the layer of material deposited on the substrate.

2. A method, as recited in claim 1, wherein the area of the shield is variable and the steps include varying the area of the shield in accordance with the size of the substrate portions selected to be shaded.

3. A method, as recited in claim 1, wherein the substrate is moved intermittently past the cathode in the chamber.

4. A method, as recited in claim 1, wherein the substrate is moved continuously through the bombardment chamber.

5. A method, as recited in claim 3, wherein the chamber contains a plurality of cathodes.

6. A method, as recited in claim 1, comprising the further steps of:

determining the material thickness contours which are characteristic of the deposition method in the absence of the shield; and
configuring the shield accordingly to provide uniform deposition.

7. An improved apparatus for depositing material on a moving substrate, wherein a cathode acts as a source of material, and wherein a layer of the material is deposited on the substrate by ion bombardment of the cathode in a chamber, wherein the improvement comprises:

a shield in the chamber for shading selected portions of the substrate, the configuration of the shield being determined by the variations in the deposit thickness which would occur in the absence of said shield; and

means for positioning the shield between the cathode and the substrate during selected intervals of bombardment, to increase the uniformity of the layer of the material deposited on the substrate.

8. An apparatus, as recited in claim 7, wherein the shield comprises:

at least two portions positioned for overlapping relationship; and

means for adjusting the amount of the overlap, and thereby the effective area of the shield, to correspond to the portions of the substrate selected for shading.

9. An apparatus, as recited in claim 7, wherein the positioning means comprises:

a fluid power cylinder mounted on the sputtering chamber, said cylinder having a piston rod extending therefrom into the bombardment chamber for supporting the shield therein;

means for limiting the extent to which the piston rod is inserted into the chamber to position the shield in relation to the substrate; and

means for actuating the piston rod to insert and withdraw the shield at preselected intervals from between the cathode and the substrate so that the selected portions of the substrate are shaded.

10. An apparatus, as recited in claim 9, wherein at least two fluid power cylinders and shields are mounted in cooperating relationship to permit adjusting the size of the area which will be shaded.

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