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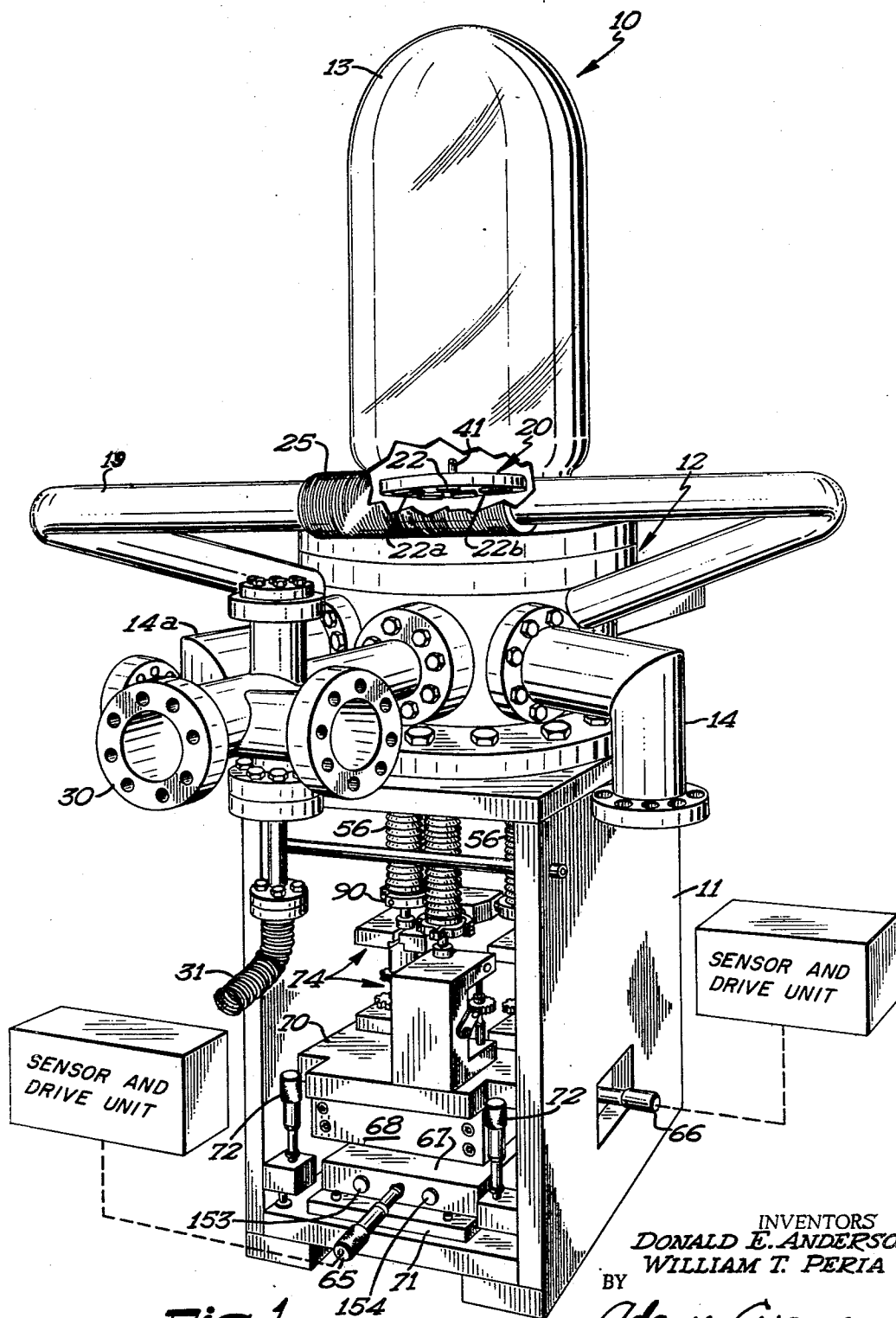
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3,494,853

VACUUM DEPOSITION APPARATUS INCLUDING A PROGRAMMED MASK MEANS
HAVING A CLOSED FEEDBACK CONTROL SYSTEM

Filed June 30, 1967

6 Sheets-Sheet 1



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6 Sheets-Sheet 2

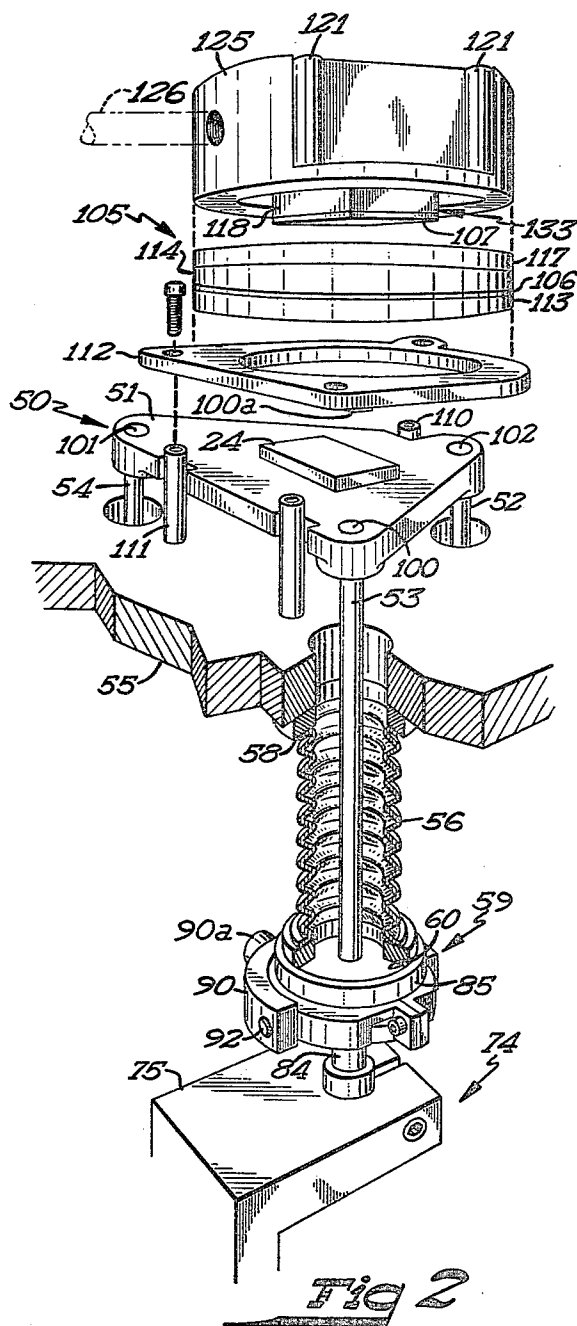


Fig 2

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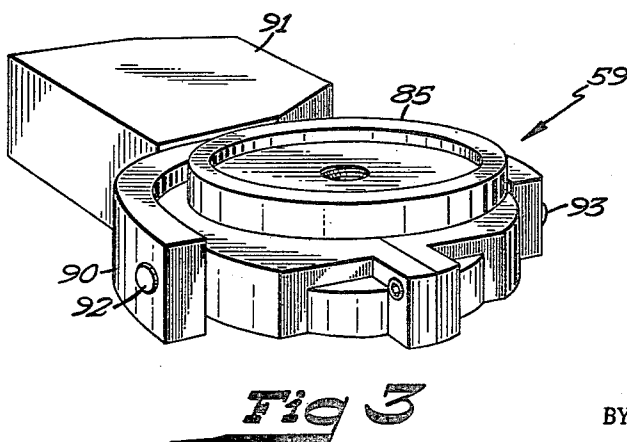
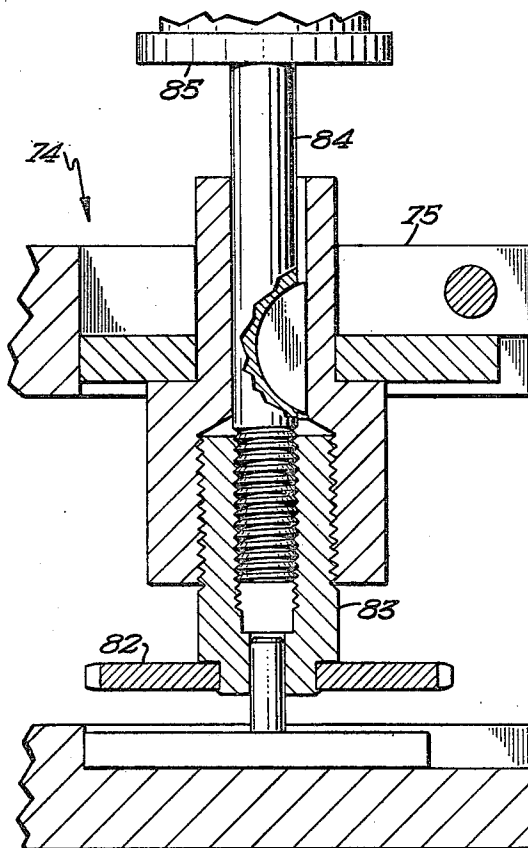
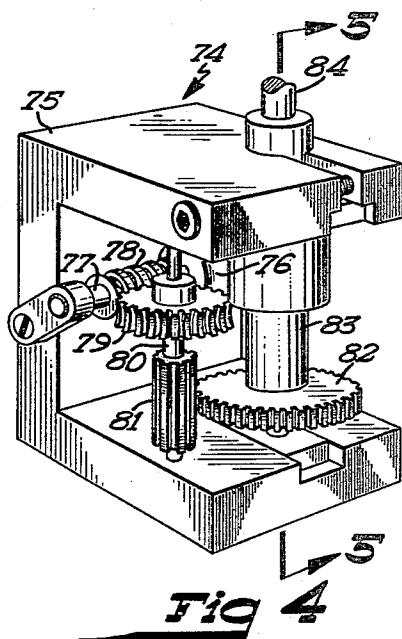
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6 Sheets-Sheet 4

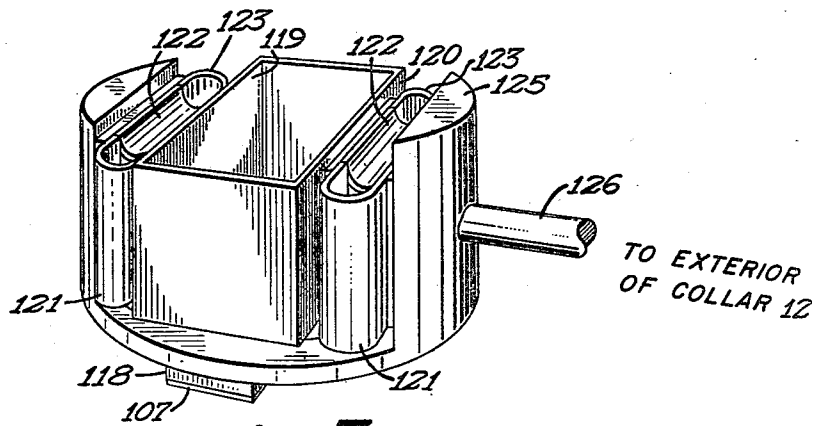


Fig 7

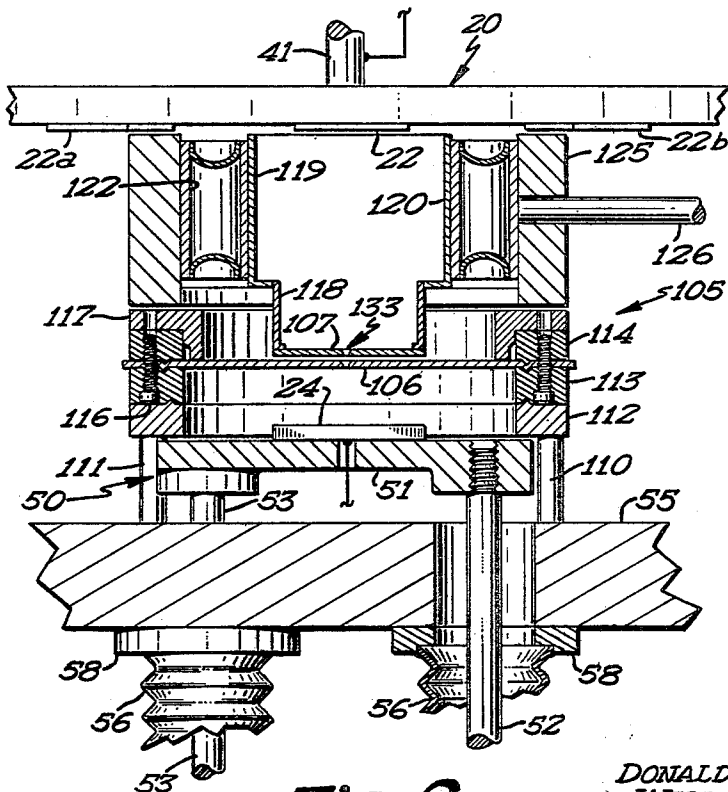


Fig 6

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6 Sheets-Sheet 5

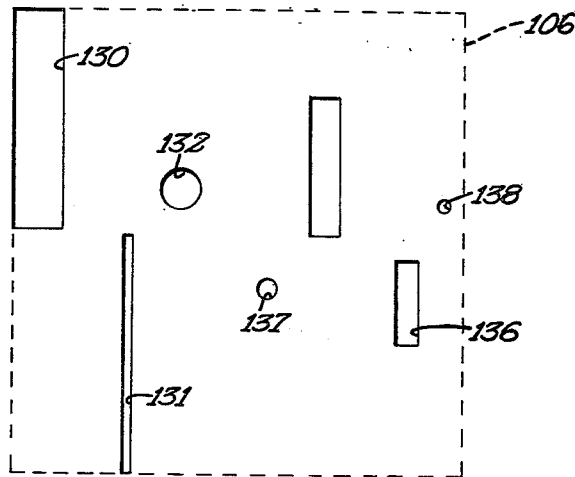


Fig 8

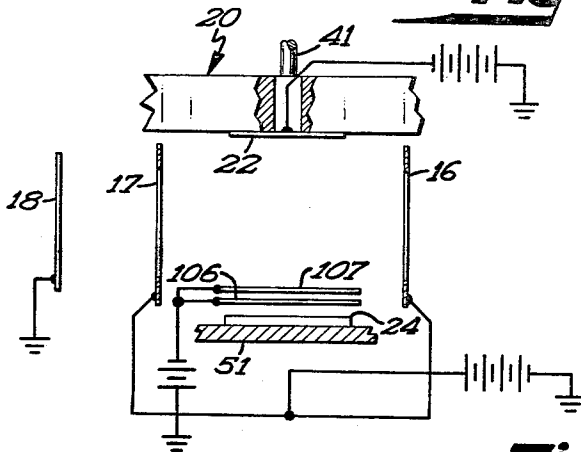


Fig 10

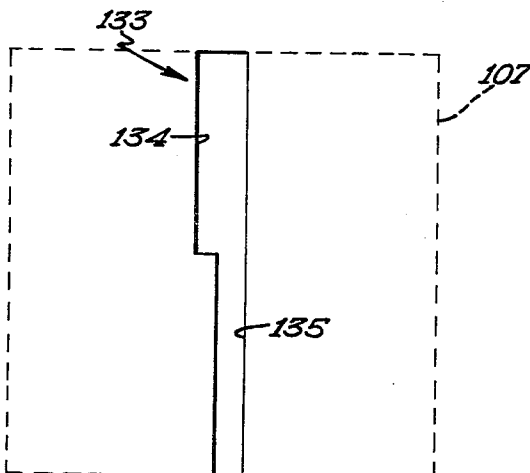
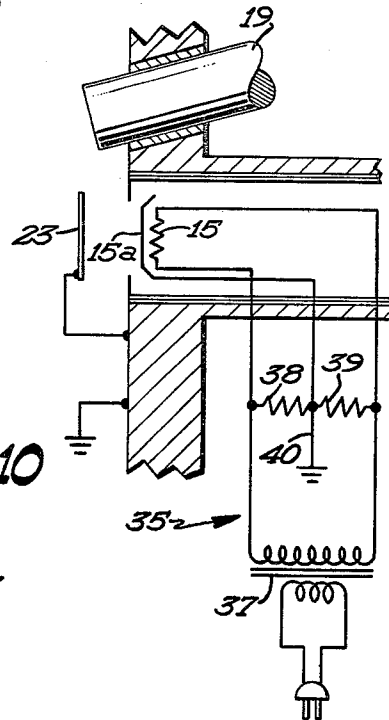


Fig 9

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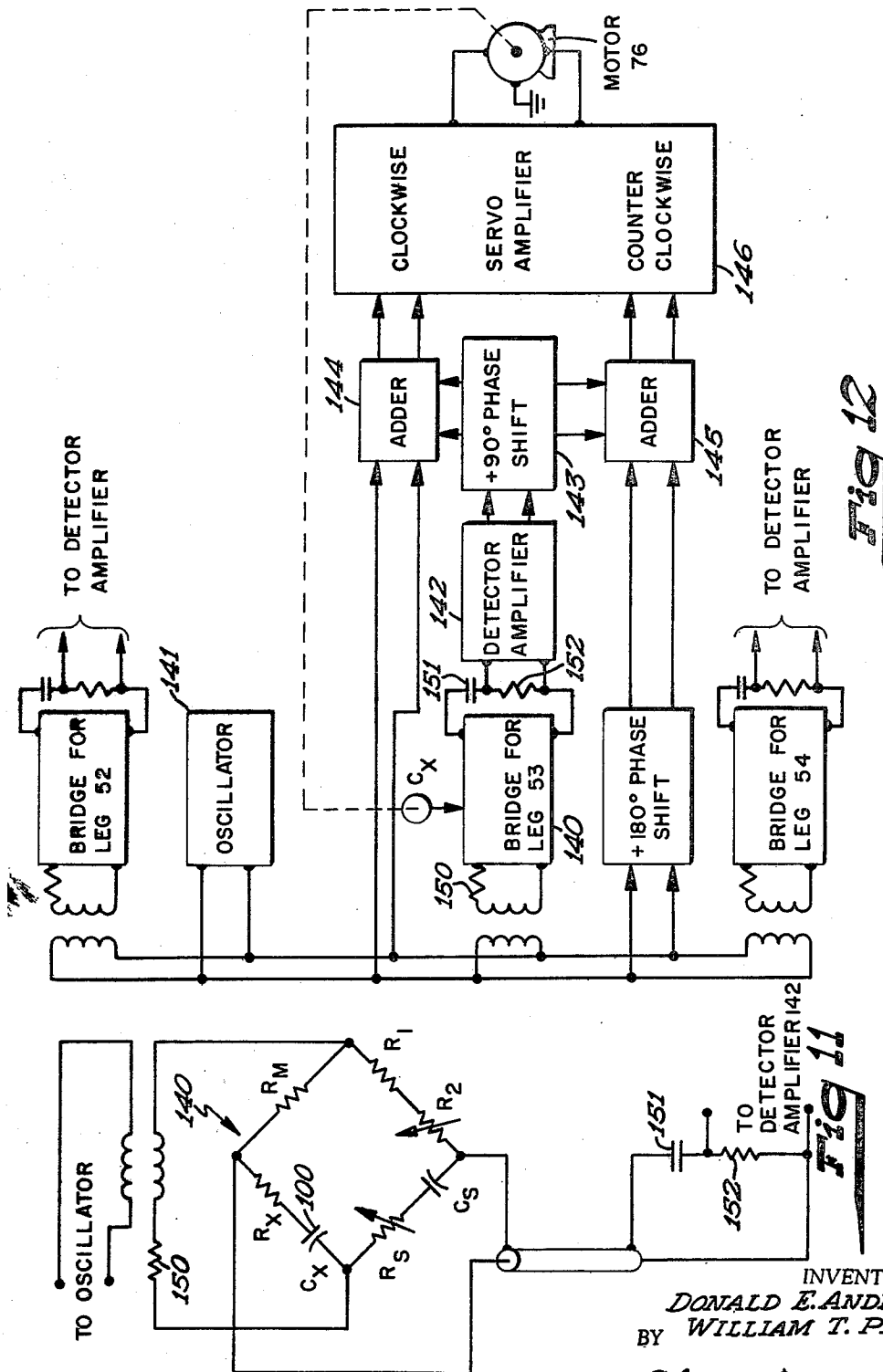
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VACUUM DEPOSITION APPARATUS INCLUDING A PROGRAMMED MASK MEANS HAVING A CLOSED FEEDBACK CONTROL SYSTEM

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14 Claims

ABSTRACT OF THE DISCLOSURE

An apparatus for depositing delineated films from a gas where a movable mask is driven by a programmed means. A feedback system responsive to sensors provides a comparative signal to correct the driving means in maintaining the mask along a predetermined three dimensional path.

An apparatus and technique for the precise delineation of thin films of a variety of materials, including those materials required in the preparation of electrical or electronic devices having both active and passive components. The active components include semiconductors, phosphors, and other materials responsive to various forms of energy. The passive components include conductors and insulators compatible with the active components. Either individual isolated components or arrays of components may be prepared. The apparatus includes a material source and a substrate to receive a deposit. Mask means are interposed between the source and the substrate to control the form of each deposit. Means are also provided to precisely control relative motion between the mask and the substrate, and feed-back loop means responsive to this precise motion are provided to continuously monitor this motion. The mask means includes a universal mask arrangement which permits delineation of materials in any desired configuration. Sputtering may be utilized, when indicated, and other techniques may be utilized when appropriate.

The present invention relates generally to a thin film deposition system having means for providing precisely controlled motion between a substrate and a mask. A monitoring mechanism provides precise predetermined motion and positioning between the mask and the substrate, predetermined programmed motion being utilized, when desired. The preferred embodiment employs sputtering for a plurality of sequential depositions, and also a "universal" mask system to provide any desired delineation of the material being deposited.

In the past, various techniques have been proposed for providing "universal" mask arrangements for thin film deposition apparatus. Unfortunately, these techniques have not been entirely successful because of the changing conditions which develop during a deposition operation. Certain of these changes include modifications in temperatures, modifications in conditions of the plasma in a sputtering operation, as well as other functional changes. Among others, there changes in temperature and other conditions manifest themselves in a deviation in spacing between a mask surface and a substrate surface. Particularly in the case of a "universal" masking system, any variable occurring in the distance between these surfaces will, of course, result in material differences in the product obtained therefrom. By the same token, changes in plasma conditions from one run to another, will be reflected in changes in product.

In connection with the preparation of controllable and repeatable thin film microcircuits, it should be appreciated

that the surface conditions between individual layers are extremely critical. Thus, controllable surface conditions are requisite and these may be obtained only in those instances where the atmosphere has been carefully controlled and maintained during the entire preparation operation. Thus, for purposes of fine control, it is desired that the atmosphere be maintained in substantially unbroken or controllably modified condition throughout the entire preparation operation. In this way, uniformity can be achieved in the product produced, since the atmosphere will be entirely reproducible throughout the entire preparation operation, one run as compared to another.

According to this invention, therefore, it is possible to consistently and repeatedly prepare devices of controllable or ultra-high purity having interfaces with controllable or complete freedom from contamination, this being achieved by requiring only a single pump down for a plurality of sequential deposition operations involving a plurality of sources of film materials to be deposited. The mask-to-substrate distance is continuously monitored and the relative movement therebetween is carefully controlled. Thin-film microcircuits may be prepared on a desired substrate by a single pump-down, either in a vacuum or an inert deposition atmosphere. The technique precludes contamination of interfaces inherent in the devices and provides significant consistency between separate runs. Controlled introduction of atmosphere during preparation is also contemplated.

Sputtering is preferred as a deposition technique for the preparation of thin-film microcircuits for several reasons. It is appreciated that all of the materials required for microcircuits may be deposited by sputtering, this including insulators, semi-conductors, and conductors. Various compositions including binary and ternary alloys may be appropriately deposited by sputtering. Preparation of complete thin film microcircuits may require sequential depositions of such diverse materials as pure metals, alloys, elementary and compound semi-conductors, dielectrics, ferroelectrics, and ferrites. The technique of the present invention will permit these various materials to be deposited in any desired sequence, and in a desired pattern, as required, demanded or indicated by the characteristics of the finished product in a single pump-down operation.

In sputtering, the extent of the deposition of a component or materials may be accurately predicted and controlled. The rate at which atoms are ejected or removed from a target by sputtering is generally a substantially linear function of the terminal conditions on the target including the potential and the current, as well as other controllable features in the system. Appropriate predetermined deposition conditions are easily programmed and rendered reproducible, from one operation to another. Thus, a wide variety of individual devices of this kind may be fabricated based upon suitably prearranged and predetermined programs.

In order to achieve these functions, a sputtering system including multiple targets or sources, a substrate spaced from the targets for receiving the sputtered material, and a mask system interposed therebetween are utilized. The selected source or target is rigidly held during deposition within the plasma zone area, while the mask and substrate are arranged for independent relative motion, one to another. Preferably, the substrate is capable of motion along coordinates in the X, Y and Z axes, and the mask assembly or system which is capable of presenting a variety of aperture conditions is, during deposition, rigidly disposed relative to the substrate. In order to achieve universal selection of masking, such as by controlled delineation of a desired line width or configuration of component, the masking assembly includes a mask ele-

ment per se together with a superimposed or over-mask apparatus which operates as a "selector" for the main mask element. Thus, with relative motion available between the main mask and the over-mask, selection, as required by the demands of the product, may be made to provide the desired configuration to be delineated.

In accordance with the present invention, therefore, a sputtering system is provided having an anode and a cathode for generating a plasma therebetween. The plasma zone per se is adapted to be generated and exist between a spaced apart target and substrate. As is conventional in sputtering systems, the ionized gas particles bombard the surface of the charged target and sputter off atoms of the target material from the target surface. These sputtered atoms are thereafter deposited within the system, a portion of them reaching the substrate surface. The apparatus of the present invention provides a means for selecting one of several target materials, and provides means for delineating this sputtered target material on the surface of a remotely positioned substrate. Appropriate masks are arranged to control the nature of the deposit, and means including a feed-back servo system are provided for controlling the position of the substrate support relative to the remaining components of the system, and in particular to the mask surface.

Therefore, it will be appreciated that all of the above sputtering operations may be performed in this equipment in a single pump-down cycle. Thus, the various components desired in the product being formed, such as, for example, a thin-film microcircuit, may be laid down in proper sequence, and ultimately the desired product will be delivered without necessitating multiple pump-down cycles between individual sputtering operations. Thus, surface contamination, particularly surface contamination brought by exposure of the components to air or other stray atmosphere components can be virtually eliminated.

Therefore, it is a primary object of the present invention to provide an improved apparatus and technique for the elimination of thin-film articles, such as, for example, microcircuits or the like, these articles being fabricated by a vacuum deposition operation such as a sputtering operation or other controlled atmospheric deposition operation utilizing apparatus requiring only a single pump-down cycle for the entire preparation operation.

It is a further object of the present invention to provide an improved sputtering system which is provided with multiple targets or sources, a substrate support table, and a mask system, the substrate support table being arranged and adapted for controlled motion along the mutually orthogonal X, Y and Z axes, the mask assembly being adapted for predetermined selection of the configuration for the pattern to be delineated.

It is yet a further object of the present invention to provide a sputtering system having a changeable and universal mask and having means providing relative movement of the substrate with respect to the mask such as a movable substrate support table, this support table being carefully and controllably movable along mutually orthogonal axes and being provided with a sensing means for positioning and maintaining the substrate support table in a precise position relative to the masking array.

It is a yet a further object of the present invention to provide an improved apparatus and technique for sputtering which utilizes a scheme for the prevention of the deposition of material onto the edges or other surfaces of the masks, such as by the application of a potential to the masks as well as other internal components of the system with necessitating complete disassembly or disruption of the atmosphere within the sputtering apparatus.

It is still a further object to prepare circuit devices having improved and unusual properties, and which devices may be consistently and repeatedly prepared.

Other and further objects of the present invention will become apparent to those skilled in the art upon a study

of the following specification, appended claims, and accompanying drawings, wherein:

FIGURE 1 is a perspective view, partially broken away, of a sputtering system prepared in accordance with the present invention;

FIGURE 2 is a detail perspective view, in partially exploded form, showing the mechanism for controlling a portion of the motion available in the substrate support table;

FIGURE 3 is a detail view of a gimbal support mechanism utilized for supporting the substrate support table;

FIGURE 4 is a detail view of a differential screw mechanism which is utilized to control the raising and lowering of the substrate support table;

FIGURE 5 is a vertical sectional view taken along the lines and in the direction of the arrows 5—5 of FIGURE 4;

FIGURE 6 is a detail elevational view, showing a desired mask assembly which is utilized in connection with the apparatus of the present invention;

FIGURE 7 is a detail elevational view of the mounting arrangement utilized for the over-mask portion of the mask assembly;

FIGURES 8 and 9 are respectively detail elevational views of one desired configuration for a mask and over-mask combination;

FIGURE 10 is a schematic of the electrical system utilized in the sputtering assembly of the present invention, and illustrating certain of the individual components therein;

FIGURE 11 is a schematic illustration of a capacitance bridge used for sensing the position of the substrate along the X, Y and Z axes; and

FIGURE 12 is a block diagram of the sensing and drive mechanism utilized for controlling the disposition of the substrate support table along one of its axes.

In accordance with one preferred modification of the present invention, the sputtering stand generally designated 10 includes a support enclosure member 11 upon which rests a collar member 12, the collar member 12 in turn supporting the bell jar 13 on the upper surface thereof. The various components which are utilized to perform the sputtering operations are disposed generally within the collar member 12, enclosure 11 being utilized to house the mechanism for controlling the motion of the substrate support table, to be more fully described hereinafter. Since most of the sputtering components are confined within the collar member 12, the bell jar 13 provides a means for sealing the system and may otherwise be utilized as a ballast zone for the gas supply required in the sputtering system, and furthermore provides a means to visually inspect the sputtering operation while it is in progress.

In a typical sputtering operation, ion bombardment is utilized to remove atoms of material from an appropriate preselected target. This ion bombardment is normally accomplished in a low pressure supported gas discharge in which a high intensity plasma is generated in an inert gas such as, for example, argon. This discharge is generally formed by means of discharging electrons from a heated thermionic cathode and accelerating these electrons by means of appropriately positioned anodes. Frequently, a magnetic field is utilized to constrain, form, or otherwise maintain the discharge, as required. As an alternative technique, a supported discharge may be provided by means of discharging radio frequency energy between spaced apart electrodes, the target material being utilized as the material for at least one of the electrodes, and preferably for each of the electrodes. This latter system is particularly adapted for use in connection with the sputtering of semi-conductor or dielectric materials, however it is adaptable for use with conductors as well. It will be appreciated, therefore, that various forms of sputtering may be used to perform the removal and depositing operation.

In the embodiment illustrated herein, particularly as illustrated in FIGURES 1 and 10, the sputtering is accomplished by means of a low pressure supported gaseous discharge between a thermionic cathode and a pair of remotely positioned or disposed anodes. With particular attention being directed to FIGURE 10 of the drawings, it will be observed that the system employs a thermionic cathode 15a having a cathode heater 15, a pair of ring anodes 16 and 17 and a remotely disposed "virtual" cathode 18. The electrons are emitted from the thermionic cathode and are accelerated by the remotely disposed anode rings 16 and 17. Any electrons passing beyond anode 17 will be repelled by virtual cathode 18, and thus enrich, or otherwise increase the effectiveness of the cathode member 15a. If desired, virtual cathode 18 may be a second thermionic source. Electromagnet 19, as shown in FIGURE 1, which is disposed externally of the collar member 12, will be utilized to constrain, or otherwise conform the plasma to a desired zone. The field from electromagnet 19 may preferably be disposed generally parallel to the axis of the plasma, but may, for some purposes, be disposed transversely thereto. The target holder generally designated 20 is shown with target 22 disposed adjacent the plasma zone, and likewise adjacent the mask-substrate portions of the assembly. As is conventional, a portion of the material which is sputter-removed from the target 22 will find its way onto the surface of substrate 24. If desired, a heat shield such as shown at 23 may be utilized to shield the plasma from thermionic cathode 15a.

Electromagnet 19 is energized by means of the helically wound coil member 25. The plasma can be effectively controlled by other means, as are known in the art, such as, and including, the control of the temperature of the thermionic emitter or emitters, the temperature and/or pressure of the gas within the zone, and the relative potentials applied on the anode rings. Permanent magnets may also be employed, if desired, to control the plasma configuration. As is shown in FIGURE 1, the cathode is conveniently disposed within the fitting 14, and the virtual cathode or second thermionic cathode is disposed within the confines of fitting 14a. Electrical lead-in conductors or devices are provided, as required for the system, these lead-in conductors or devices not being shown in FIGURE 1.

As materials of construction, the bell jar should be preferably fabricated of an impermeable material such as a hard glass or stainless steel, and equipped with a stainless steel flange for mounting on the collar. The components retained within the vacuum system are preferably stainless steel, as is conventional in most vacuum systems.

The atmosphere for the system is controlled through a fitting generally designated 30, this fitting being capable of coupling to an evacuation system, not shown, and also being capable of coupling to a source of inert gas, such as argon, preferably through the conduit system 31. As a requirement of the system, extremely pure argon gas should be utilized, this gas being available from a commercial source of argon, and preferably being treated in a cataphoresis tube to increase its purity prior to introduction into the system. Getters, as desired, may be employed within the confines of the system.

In a typical operation, the thermionic cathode will be coupled to the electrical system shown generally as 35, and including a transformer 37, the secondary of which is coupled to a pair of series-coupled resistors 38 and 39, the junction point of these being grounded as at 40. The resistor members 38 and 39 are effectively in parallel with the leads of the cathode heater 15 and the cathode 15a is connected to the junction point of resistors 38 and 39. The anodes are preferably run at a potential of between 30 and 50 volts positive, and the virtual cathode is run at either ground potential or, as previously in-

dicated, may be a second thermionic cathode similar to cathode 15. The target 22 is, in this system, held at a negative potential of between about 750 to about 1000 volts. The external magnetic field, adequate to control this discharge effectively, is in the range of between about 300-500 gauss with the system being filled with pure argon at a pressure between 5×10^{-3} and about 5×10^{-4} Torr.

With particular attention being directed to the mechanism for carrying the multiple targets as shown in FIGURES 1 and 10, it will be appreciated that any of a variety of schemes may be utilized. One scheme which has been found particularly suitable is in the form of a rotating carrier member such as the axially rotatable carrier member 20. Carrier 20 is rotatable about a vertical shaft 41, and is provided with a plurality of target holders or supports about the periphery thereof, each target being sufficiently large to provide a substantially parallel beam of sputtered material to the substrate surface. As illustrated in FIGURE 6, targets are secured about the periphery of carrier 20, such as are illustrated at 22, 42a and 42b inclusive. Suitable target supports are provided such as firm clip type retainers or the like, and means are also provided for establishing an electrical bias on each of the individual targets. In a typical sputtering operation for the fabrication of thin-film microcircuits, a plurality of targets will be required; two targets may be of a semiconductor base material, such as, for example, one ultra-high purity silicon, and one doped silicon. In the apparatus of FIGURE 6, the former may be disposed at station 22a, the latter at 22b. A dielectric substance may be disposed at a different station or position. In order to adequately sputter such a material, a source of R-F energy should be coupled to the surface of the target, such as is disclosed in the co-pending application of Nils Laegreid and Roger Moseson, Ser. No. 352,415, filed Mar. 2, 1964. A conductor material, as desired, may be disposed at 46 and 47. Suitable conductors may be, for example, copper, silver, or the like, and may also be a material consisting of alloys of these materials.

The substrate support mechanism

As previously indicated, the substrate support is capable of motion along three axes or coordinates of planes, this motion being described herein as being along or in the X, Y and Z planes. Horizontal movement provides the relative motion between the mask and substrate in a direction normal to the sputtering direction and vertical movement parallel to the sputtering direction, controls or determines the mask-to-substrate spacing. With particular attention being directed to FIGURES 1 and 2 of the drawings, the substrate support system generally designated 50 includes a table member 51 upon which may be mounted the substrate 24. Table 51 is in turn supported by the legs 52, 53 and 54, these legs passing through appropriate bores formed in base block 55. In order to protect the environmental atmosphere within the sputtering chamber, appropriate bellows seals such as the bellows 56 are positioned to provide a flexible lock for the support legs, as is conventional in systems of this type. Bellows 56 are secured by means of appropriate techniques such as welding to the base 55 as at 58, and are in turn coupled to the underside of the support plate or platform 59 as at and along the bond at 60.

As previously indicated, the support table is movable along three axes, such as along or in the X, Y and Z axes or coordinates of planes. The motion and the positioning of the substrate support are each precisely and constantly controlled. While each direction of motion or translation is preferably achieved by similar means, this embodiment illustrates the translation in the horizontal direction or along the X and Y planes are being accomplished by appropriately driven micrometers 65 and 66, these micrometers driving the support plates for these translational stages 67 and 68 respectively. Movement in the horizontal direction provides the relative motion

between the mask assembly and the substrate. A base plate 70 is arranged on top of the translational stage plates 67 and 68, as indicated, plate 67 being supported on the foundation plate 71. Plate 71 may be appropriately leveled by the individual leveling micrometers 72-72. The top surface of plate 70 is provided with three leg support assemblies, each being generally designated 74-74. Each of these assemblies 74 includes a base mounting bracket 75, together with an arrangement for controlling the elevation along the vertical or Z axis. This control is achieved by means of the system shown in FIGURES 11 and 12 and includes a closed loop feed-back servo system using a capacitive sensing element to sense and thereby maintain and control the mask-substrate spacing. Control to within a tolerance of 500 angstrom units may be achieved. The detecting and driving circuits as indicated are shown in FIGURES 11 and 12, and the mechanical motion portion of the system is best shown in FIGURES 2, 4 and 5. As previously indicated, a similar feed-back system may be utilized for controlling the motion in the X and Y planes, the system being provided with modified sensing means such as, for example, a monochromatic interferometer or the like. Only the drive and feed-back system utilized for the Z axis will be described, it being understood that similar systems are provided for the X and Y stages. Referring to FIGURE 4, the mechanical drive portion is powered by the motor 76 which is mounted on the bracket 75, motor 76 having a shaft extension 77 carrying the worm gear 78. The free end of the shaft 77 is mounted within a suitable bearing structure, as shown. Worm 78 engages gear 79 which is mounted on and secured to shaft 80 carrying the drive pinion portion 81. Pinion 81 engages the drive gear 82, causing rotation of the differential screw mechanism formed by the threaded shafts 83 and 84 (FIGURE 5). Shaft portion 84 is secured for axial movement to cap member 85, cap member 85 being utilized as a support for the platform 59. (Practical ratios of threads in differential screw arrangement is 63 and 64 threads/inch, giving a ΔL of 0.248 mil/turn of shaft.)

The details of the platform system 59 are shown generally in FIGURE 3. This platform support includes a gimbal type support, the gimbal mechanism including yoke 90 which is provided with a pin member or extension 90a (shown in FIGURE 2) arranged to be received within a bore formed in the head 91. This pin is, of course, free for axial rotation about a horizontal axis. The free ends of the yoke 90 are each provided with bores for receiving the stub shafts 92 and 93 therewithin, and at right angles to the pin member or extension, stub shafts 92 and 93 serving to support the platform 59. Thus, the individual support legs 52, 53 and 54 may be received within the upper surface of the platform 59 and can be accordingly raised and lowered, as desired and be disposed at any desired angle to the horizontal.

The drive mechanism for the motor 76 is shown in FIGURES 2, 11 and 12, and will be described at this time. Individual capacitive sensors are disposed at and along the upper surface of support table 51, one plate of these sensors being shown at 100, 101 and 102. These sensor plates form one-half of an air-gap capacitive sensor, the other plate or probe pin being disposed along the surface of the support ring member 112. These plates, for example 100a, or alternatively probe pins, which cooperate with plates 100, 101 and 102, may be substantially identical to those shown at 100, 101 and 102 and oppositely disposed thereto. It will be understood that the size of the capacitive sensors must be such that relative motion between the mask surface and the substrate surface will not alter the signal values. This may be done by a variety of methods, including the use of a probe for one of the capacitor plate pairs, if desired.

It will be appreciated that the means for providing motion in the Z axis may be provided with independent means for controlling the disposition of the substrate

relative to the mask assembly. This feature may be desirable in order to make possible the canting or tilting of the mask assembly relative to the substrate, and thereby provide for parallel disposition between the two members. It will be appreciated that the concept may also be utilized to provide for anomalous characteristics in the film being deposited.

It is also recognized that the apparatus detects the relative distance between the substrate support and the mask surfaces. Care must be exercised in order to obtain a substrate which is extremely uniform and planar in order that the careful control exercised on the spacing between the substrate support and the mask will be accurately reflected in the spacing existing between the substrate surface and the mask surface.

Mask system arrangement

Particular attention is now directed to FIGURES 6-9 of the drawings which disclose in detail the arrangement of the mask assembly or system. The system is shown generally in FIGURE 6 at 105, and includes a main mask member 106 together with a cooperating over-mask member 107. The two masks are positioned, as indicated, in superimposed relationship between the target and the substrate. Mask 106 is supported on the table 55 by three stand-off elements or posts, such as are shown at 110 and 111. The length of these three stand-off elements or posts will determine, to a rough extent, the mask-to-substrate dimension. When significantly different dimensions are contemplated, a separate set of stand-off elements or posts will, of course, be utilized. These stand-off elements or posts support a first support ring member 112 which is coupled to a pair of separable rings 113 and 114, these rings 113 and 114 being capable of separation by means of the threaded screws indicated in FIGURE 6 as at 116. An upper support flange 117 is secured to the surface of the mask 106, and is utilized to assist in proper guiding of the mask 106 in the system. Suitable guiding gussets are utilized in order to obtain proper inter-registration of the rings 113 and 114.

Over-mask 107 is arranged in superimposed relationship to the mask 106, and is adapted for relative motion along one horizontal axis, such as along the X axis. This mask 107 is mounted in a retaining member 118, as indicated, the member 118 having a pair of upstanding surfaces 119 and 120 which are disposed in contact with a spring guide assembly which includes four half-cylinder or single-flex axis spring members such as the spring members 121, 122 and 123. These spring members retain the over-mask assembly in proper predetermined relationship in an environment capable of being subjected to significant vibrational forces. It will be appreciated that the arrangement of these springs is such that relative motion along either the Y and Z axes is not possible. This assembly is held in the retaining member 125, and relative motion in the X axis is provided by means of the control shaft 126. Appropriate bellows seal arrangement is provided for permitting the motion of the rod 126.

Attention is now directed to FIGURES 8 and 9 for a showing of the mask and over-mask configurations. While it will be appreciated that various selected configurations may be utilized, those shown in FIGURES 8 and 9 are capable of providing a universal masking capability of substantially infinitely variable form for the system. FIGURE 8 includes a plurality of apertures or ports, such as the apertures 130, 131, 132 and the like. The over-mask assembly includes an elongated slot generally designated 133 and having a relatively wide segment 134 along with a relatively narrow segment 135. The typical masking system would provide for a number of mask arrays to be formed in a single mask unit. Thus, multiple structures of identical form could be provided on a repeating basis in individual substrate members, as may be desired. Of course, it will be appre-

ciated that modified mask arrays, different, one from another, may be provided if necessary.

The apertures in the mask are preferably tapered in form along the depth axis of the aperture. This provides a more predictable and consistent opening dimension in the apertures, and a more extensive lifetime, consistent with a minimum of loading of the bores of the apertures during use. Thus, the sputtered material will not tend to build up along the surface of the apertures and thereby clog or partially clog the aperture, thereby leading to inconsistent or unpredictable results. A preferred mask design is one which utilizes a main aperture or ultimate opening prepared from electroplated nickel or 1 mil stainless steel as a facing, this being provided with a back-up member of heavier, substantially pure copper or the like. As an alternate or added technique for controlling or eliminating build-up on the mask surfaces, a biasing potential may be applied to the mask, and thereby provide what is believed to be a back-sputtering of any material, atomic or a moiety of material, which may tend to build up or deposit thereon. This system provides for consistently clean apertures. A negative potential in the range of about 80 volts has been found optimum for a copper-electroplated nickel system used while sputtering silicon, this being the potential useful in the system described herein. Obviously, different systems, different materials being sputtered, different mask materials, and other variations will require different potentials to be used, it being understood that a weaker potential may not eliminate buildup effectively in certain systems, and a significantly greater potential may tend to sputter-remove the masking material per se, thereby tending to contaminate the system and interfere with its normal operation.

In a typical operation, the over-mask, which operates as a selector mask, is moved into position over the appropriate aperture in the mask 106. Relative motion between the mask and over-mask elements is provided, as indicated, wherein over-mask 107 is adapted for motion along one horizontal axis. The disposition of the over-mask, relative to the mask, will provide the preselected aperture for the mask-over-mask combination. Before commencing the operation of the deposition equipment, the over-mask will be arranged in suitable disposition, superimposed over the mask element 106. As indicated, the individual apertures 130, 131 and 132 on the surface of the mask 106 are staggered along the axis of motion of the over-mask 107, thereby permitting access only one predetermined aperture in the mask 106. As is indicated, these apertures in mask 106 are of various sizes, including the rectangular configurations at 130, 131 and 136, and the circular apertures at 132, 137 and 138.

In order to consistently maintain the apparatus, it is generally desirable to arrange for removal of the over-mask 107. This is preferably accomplished by rendering the rod 126 movable by way of a bellows sealed coupling, connection or the like in order to permit periodic removal of the over-mask from the masking area. This permits appropriate pre-cleaning of the substrate, such as by back-sputtering the substrate surface, and also facilitates encapsulation of the final device. In the absence of such a feature, the system may be appropriately taken apart and cleaned by conventional techniques and methods.

It will be appreciated that the low pressure in the enclosure will assist in providing or maintaining a relatively constant inwardly directed mechanical bias on the rod 126, provided a flexible bellows-type seal is utilized.

Masks in the present system may be changed, as desired. It is only essential that the new mask be capable of being retained within the ring members 113 and 114, as illustrated in FIGURE 6. Also, it may be desirable to provide means which would permit blanket coating of a substrate or product surface. Such an arrangement may be desirable in certain microcircuitry preparation opera-

tions, particularly when conductors are being formed on the surface and when a device is being encapsulated. It will be further appreciated that any mask must be retained tautly within the confines of the rings 113 and 114 in order to prevent sagging of the masks within the confines of these rings.

Generally, for most applications, a mask-to-substrate distance of about 0.25 mil is employed. Obviously, various other distances may be utilized, as desired, depending upon the preparation techniques being utilized.

In a typical mask array, the gap opening or width of the individual apertures will vary according to the requirements of the system, however, a typical mask for microcircuitry will utilize a slot width of about 9 mils in the aperture 130 and only about 1 mil in aperture 131. The circular openings may vary in diameter from about 8 mils for opening 132, down to 1 mil for opening 138. This selection will provide a substantially "universal" system.

Certainly, the ultimate use and purpose of an operation may dictate that various patterns be utilized, depending upon the ultimate structure being prepared. In each and every instance, the feature that must be carefully observed and controlled is the substrate-mask distance. In addition to the careful control of this distance, it is also generally essential that a controlled parallel disposition is provided between the substrate and the mask. As previously indicated, some departure from parallel, if controlled, may be desirable in certain instances.

Thus, means for providing mechanical translations along the X and Y axes are available. In accomplishing this motion, the X axis motion will be manifested by translation of the staging plate 67 relative to the base plate 71. The Y axis translation will occur by virtue of the translation of staging plate 68, relative to the staging plate 67. Motion in either the X axis or the Y axis will be manifested or reflected in the corresponding motion of the base plate 70.

Operation of closed loop feed-back servo system

As indicated in this apparatus, the translations available in the X, Y and Z axes are preferably provided by closed loop feed-back servo systems. For the X axis and Y axis (horizontal axis or normal to the axis of sputtering), motion may be provided by means of the mechanically driven micrometer elements 65 and 66; however, in the alternative, an optical indexing system utilizing two pairs of spaced mirrors or the like, may be used. If desired, monochromatic light energy may be utilized to advantage in the optical indexing system. For the Z axis sensing (the mask-to-substrate distance), capacitive sensing elements may be employed at three spaced locations on the substrate table. For various operations and applications, the X and Y directional translations which employ micrometer drives for each translational stage may be adequate. Micrometer drives having accuracies to within about 0.0001 inch are commercially available.

With particular attention now being directed to FIGURES 11 and 12, a system is shown which is capable of controlling the substrate-to-mask spacing at a distance of 0.25 mil with a tolerance of about 500 Angstroms. FIGURE 11 is a schematic of the capacitance bridge utilized for the Z axis sensing, which is essential in any operation wherein temperature changes of the magnitude encountered here are experienced.

The distance sensing element in each instance is a parallel plate capacitor as shown at 100, 101 and 102 of FIGURE 2. This capacitor plate has an area of 0.1 inch square on the substrate holder 51 and a corresponding area superimposed on the mask holder 112. At a spacing of 0.25 mil, the capacitor has a value of about 8 pf. If this spacing changes by 0.01 mil, the capacitance would change by about 1 pf. This change in capacitance is accordingly monitored with the bridge structure 140

shown in FIGURE 11. Capacitive probes may be utilized as well as hereinbefore indicated.

The design of bridge 140 is patterned after a Wien capacitance bridge, is generally easy to null, and exhibits reasonable sensitivity in any change in value of capacitance in the sensor shown at 100, which corresponds to the capacitor plate Cx at FIGURE 2. When the capacitance in the capacitive sensor 100 is changed by a value of 1 pf. from a nominal value of 8 pf., the bridge output is about 15 mv. This signal is shifted in phase with respect to the input by about 80 degrees, the direction of shift depending upon whether the spacing is less than or greater than the original or desired value. An oscillator 141, two adding networks 144 and 145, and a servo amplifier 146 complete one channel of the system, it being understood that one channel is required for each leg of the assembly. This additional circuitry, which is conventional in nature, is shown in block diagram form in FIGURE 12. Capacitance-controlled servo systems of the type shown in FIGURE 12 are commercially available.

The source of input energy to the bridge configuration for leg 53, as shown, is provided by the oscillator 141. Upon flow of this energy through the bridge configuration 140, the output from the bridge 140 is shifted 90 degrees in phase by virtue of the presence of the capacitive member therein. This bridge output is amplified in amplifier 142 and is then again shifted by 90 degrees in station 143 in order to provide it as one portion of the input to the adder stations 144 and 145 as illustrated shifted in phase by 180 degrees from the output of the oscillator 141. Input to adder 145 is already shifted by ± 180 degrees from the output of oscillator 141. This adder system is, in effect, a differential amplifier capable of providing a DC output based upon the summation of the inputs from the oscillator and from the phase shift station 143. This DC output is then passed through a clamp and peak detector found in servo amplifier station 146, and the output of which will accordingly drive the DC motor shown at 76 in either a clockwise or counter-clockwise direction. The motion provided by the motor 76 in response to the signal obtained in the Wien bridge will then be reflected in a raising or lowering of the corresponding leg 53 in the system.

In connection with the sensor circuit shown in FIGURE 11, the following values have been found appropriate for use in the circuit shown:

Component:	Value
Resistor 150 -----	150 ohms.
Capacitor 151 -----	0.1 μ f.
Resistor 152 -----	50K ohms.
R _m -----	10 megohm.
R ₁ -----	470 ohm.
R ₂ and R _s -----	500 ohm potentiometer.
C _s -----	μ f. range.

While this feed-back servo system has been described and illustrated for operation in connection with motion in the Z axis, it will be appreciated that similar mechanisms may be employed for motion in the X and Y axes. The signal inputs for controlling the motion in the X and Y axes may, of course, be derived from any of a multitude of systems. As indicated previously, this may be accomplished by means of capacitive plates, capacitive probes, optical sensing, or other techniques. In this connection, a pair of light reflecting plates 153 and 154, as shown in FIGURE 1, may be employed to detect translational motion in the X and Y axes or directions.

General considerations

As previously indicated, a back-bias may be placed upon the mask assembly in order to prevent any build-up of sputtered material. This same feature may be utilized in somewhat modified form in connection with the substrate. A lead, as indicated in FIGURE 6, is arranged to pass through the substrate holder, and make contact with

the substrate member per se. With a suitable insulating film between the substrate and the substrate support, a potential may be applied to the substrate in order to provide for initial sputtering of the substrate surface for purposes of obtaining clean, contamination-free surfaces. This feature may be of considerable value when consideration is given to the preparation of the application of materials to surfaces which may bond with difficulty to an oxide or contaminated film.

While the structure has been discussed in connection with a passive substrate member, it will be appreciated that the system is equally workable with active substrates. Again, the back-biasing of the substrate to accomplish back-sputtering or surface cleaning may become desirable when active substrates are being employed and considered, this operation being capable of enhancing the consistency of the individual units, particularly in the bonding between the individual layers formed therein.

The apparatus of the present invention is adapted for use in connection with the discretionary wiring of micro-circuit chips. In such an operation, a testing system is provided for the system, and this testing is accomplished during or after the preparation of the individual micro-circuits, and with the use of suitable data processing techniques, the ultimate circuit pattern is arranged and designed to provide an interconnect system which results in a product having the circuit parameters desired. This particular system would still make it possible to prepare and test the individual microcircuits, and thereafter arrange the interconnects, as needed, in a single pump-down operation.

In order to properly program the motion of the substrate during the preparation of the various devices, a predetermined program is entered into a suitable drive mechanism to arrange the desired outputs. These outputs are then coupled into the X and Y translational stages, and motion is available between the mask and the substrate. The drive mechanism will generally employ a predetermined drive arrangement which will feed information to a motor drive for actuating the micrometer drives 65 and 66. This motion is monitored or otherwise controlled by means of the optical indexing system, as indicated, and the resultant drive is accordingly carefully and controllably carried out.

As previously indicated, the deposition system of the present invention is preferably conducted with a sputtering technique. In certain applications and operations, it may be desirable to employ an alternate deposition scheme for application of a final or uniform film layer to the product. Thus, an alternate system, such as an evaporative system, may be provided having a single mask or a plurality of masks for individual depositing operations.

Product characteristics

The characteristics of products obtained from the present apparatus are generally highly desirable. These properties are reflected in improved electrical parameters for devices formed in accordance with the apparatus and technique disclosed herein. The system permits controlled nucleation of the film being prepared, thus permitting the preparation of single crystal films on various substrate surfaces, including amorphous substrate surfaces.

A further capability of this apparatus is the preparation of solid state interfaces which can be kept essentially free of contamination, or, when desirable, deliberately contaminated or doped in accordance with a prescribed technique. Thus, it is possible to obtain a p-n junction in a semiconductor device wherein the plane of the junction is normal to the broad or major surfaces of the device. Conventional methods utilizing junction planes parallel to the surface normally require a considerable device thickness to achieve, for example, an ordinary bipolar transistor.

Because of the close control exercised over the deposition operation, operations may be carried out wherein

the delineated films are carefully prepared with regard to composition and configuration. Thus, the properties of devices obtained as a result of this careful control are significantly uniform, and predictable, from one preparation operation to another.

It will be appreciated that the various specific examples provided herein are for purposes of illustration only, and those skilled in the art may reasonably depart from these examples without necessarily departing from the spirit and scope of the present invention.

What is claimed is:

1. In a deposition system having means defining a deposition chamber and means to evacuate said chamber:

- (a) means for establishing a gaseous flow of material to be deposited under reduced pressure from a source to a substrate, and defining a deposition zone therebetween;
- (b) means for supporting a substrate for receiving material as a deposit thereon;
- (c) mask means interposed between said source and said substrate, said mask means having means for providing a predetermined aperture lying in a path between said source and the surface of said substrate; and
- (d) means providing relative motion between said mask system and the surface of said substrate and including a drive element for providing motion along a predetermined axis, sensor means for substantially continuously sensing the position of said mask means relative to said substrate support for providing a signal in response to said relative position, and means responsive to said sensor signal for energizing said drive element in response to the immediate magnitude of said signal.

2. The deposition system as defined in claim 1 being particularly characterized in that the relative motion between said mask means and said substrate is provided by a drive element coupled to said substrate support means.

3. The deposition system as defined in claim 1 being particularly characterized in that relative motion is provided between said mask means and said substrate by drive elements coupled to said substrate support means for providing motion along a plurality of individual axes.

4. The deposition system as defined in claim 1 being particularly characterized in that a plurality of sources of material to be deposited are provided within said chamber, each of said sources having a composition which is different, one from another.

5. The deposition system as defined in claim 1 being particularly characterized in that said mask means includes a first mask having an array of apertures of predetermined pattern extending therethrough, a second mask having a selector aperture formed therethrough, said selector aperture being capable of being disposed in selective superimposed relationship to the apertures formed in said first mask.

6. The deposition system as defined in claim 1 being particularly characterized in that said means for providing relative motion between the mask system and the surface of the substrate includes drive elements for providing independent motion along a plurality of axes, and sensor means are provided for substantially continuously sensing the position of the mask system relative to the substrate support for providing a signal in response to the position of the substrate support relative to the mask system, and means responsive to a sensor signal along each of said plurality of axes is provided for energizing drive elements along a predetermined pattern and in response to the immediate magnitude of said sensor signal.

7. In a deposition system utilizing a low pressure supported gas discharge plasma, having means forming an enclosure for said system, means to evacuate said chamber, means for introducing an inert atmosphere of relatively low pressure to said enclosure, and means for establishing a gas discharge plasma therewithin;

(a) means for introducing and maintaining a supply of electrons to support said plasma, said plasma being of finite length and defining a reaction zone thereacross;

(b) at least one target electrode disposed along said reaction zone, and being arranged to receive gaseous ions along the surface thereof from said plasma for the sputter removal of material therefrom, means for supporting a substrate in spaced relationship from said target for receiving said removed material;

(c) mask means interposed between said target and said substrate support for controlling the deposition of said removed material onto said substrate, said mask means being movable to place an aperture of any one of various desired configurations in a common path through said aperture between the surface of said target and the surface of said substrate; and

(d) drive means for providing independent relative motion in a plurality of coordinates of planes, said drive means including sensor means for substantially continuously sensing the position of said mask means relative to said substrate support and providing a signal in response to said relative position, and means responsive to said sensor signal for energizing said drive means in a predetermined pattern and in response to the immediate magnitude of said signal.

8. The deposition system as defined in claim 7 being particularly characterized in that said drive means is coupled to said substrate support to provide motion thereto.

9. The deposition system as defined in claim 7 being particularly characterized in that said plasma is created from a plurality of electrodes including an anode for attracting electrons from said source of electrons and being disposed in spaced relationship from said electron source.

10. The deposition system as defined in claim 7 being particularly characterized in that a plurality of target electrodes are provided within said reaction zone, each of said target electrodes having a composition which is different, one from another.

11. The deposition system as defined in claim 7 being particularly characterized in that said mask means includes a first mask having an array of apertures of predetermined pattern extending therethrough, a second mask having a selector aperture formed therethrough, said selector aperture being capable of being disposed in selective superimposed relationship to the apertures formed in said first mask.

12. The deposition system as defined in claim 7 being particularly characterized in that means are provided for establishing a biasing potential on each of said mask means.

13. In a deposition system utilizing a low pressure supported gas discharge plasma having means forming an enclosure for said system, means for introducing an inert gaseous atmosphere of relatively low pressure to said enclosure, and means for establishing a gas discharge plasma therewithin;

(a) a source of electrons to support said plasma, a plurality of electrodes including an anode for attracting electrons from said electron source and being disposed in spaced relationship from said electron source to define a reaction zone therebetween;

(b) a plurality of target electrodes disposed along said reaction zone, and having means for independently biasing preselected targets relative to said plasma, each of said targets being arranged to receive charged gaseous molecules along the surface thereof from said plasma for the sputter removal of surface particles therefrom, and means for supporting a substrate in spaced relationship from said target for receiving said removed atoms;

(c) mask means interposed between said target and said substrate support means for controlling the deposition of said removed particles onto said substrate,

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said mask means including first and second mask elements, the first mask element having a plurality of aperture therein, the second mask element being movable relative to said first mask element and having a selector aperture therein for selectively exposing certain apertures in said first mask to form a common path through said mask between the surface of said target and the surface of said substrate; and
(d) said substrate support means having drive elements coupled thereto for providing independent motion in a plurality of coordinates of planes, said drive elements including sensor means for substantially continuously sensing the relative spacing existing between said first mask and said substrate support to provide a signal in response to said relative spacing, and means responsive to said sensor signal for energizing said substrate support drive elements along a predetermined path and in response to the immediate magnitude of said sensor signal.

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14. The deposition system as defined in claim 13 being particularly characterized in that means are provided for establishing a biasing potential on each of said mask means.

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117—212; 118—7, 49.5; 204—192

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,494,853

February 10, 1970

Donald E. Anderson et al.

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 40, "elimination" should read -- delineation --; line 69, "with" should read -- without --. Column 6, line 20, "42a" should read -- 22a --; line 71, "are" should read -- as --.

Signed and sealed this 17th day of November 1970.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents