

- [54] **APPARATUS FOR ETCHING OF THIN LAYERS OF MATERIAL BY ION BOMBARDMENT**
[75] Inventor: **Richard Edward Quinn**, Willingboro, N.J.
[73] Assignee: **RCA Corporation**
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- [63] Continuation-in-part of Ser. No. 612,908, Jan. 31, 1967, abandoned.
[52] U.S. Cl.....204/298
[51] Int. Cl.....C23c 15/00
[58] Field of Search.....204/192, 798

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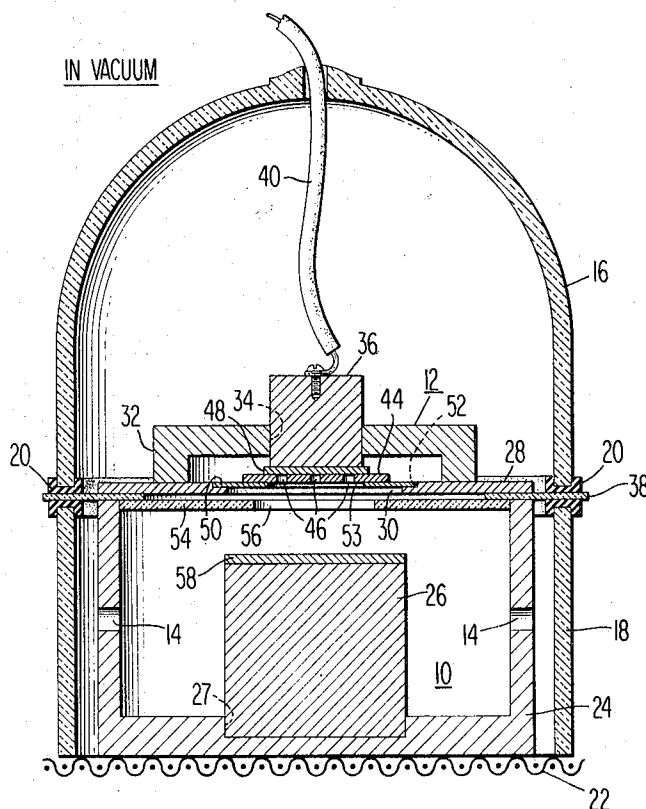
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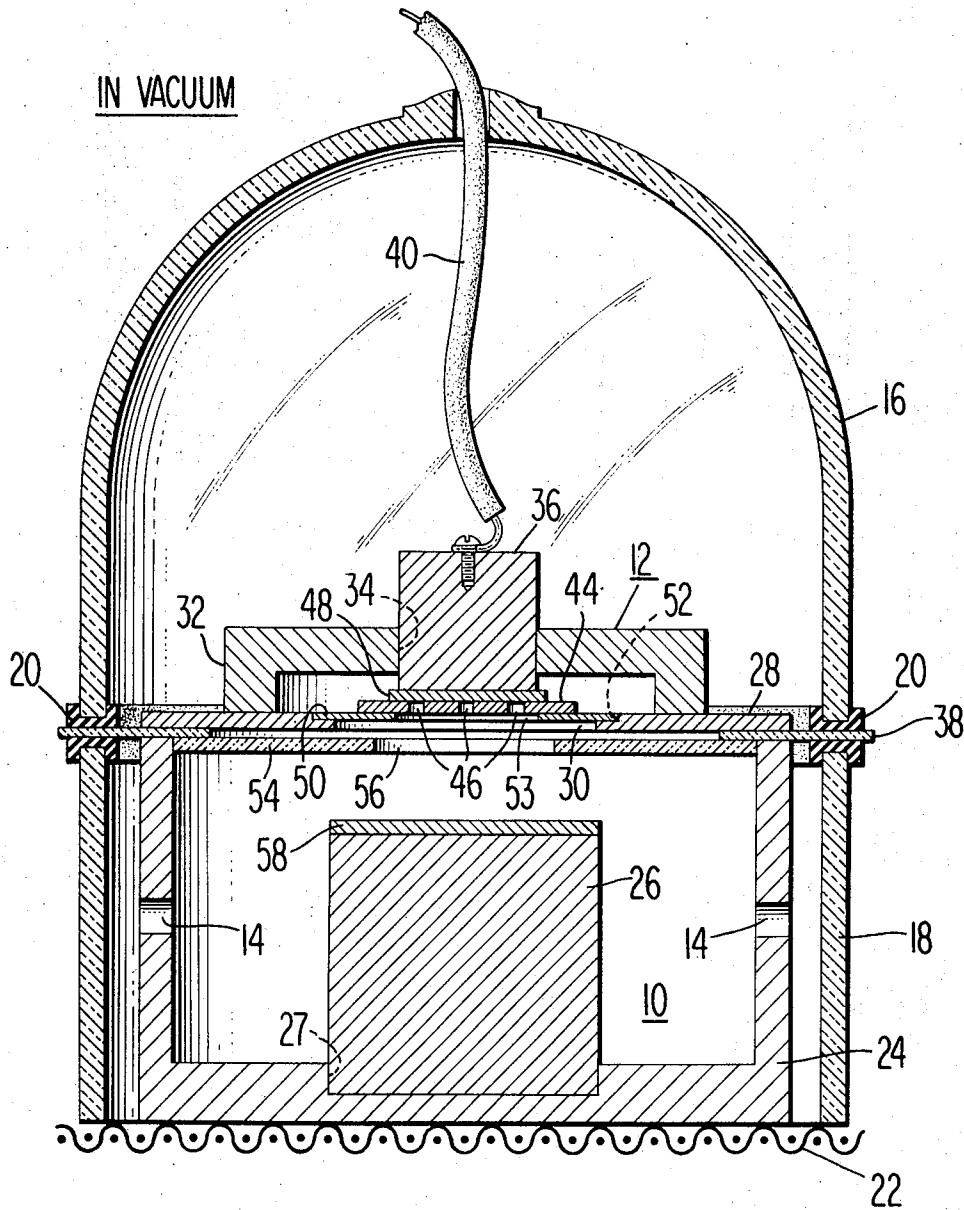
Primary Examiner—G. L. Kaplan
Assistant Examiner—Sidney S. Kanter
Attorney—Glenn H. Bruestle

[57] **ABSTRACT**

A method of etching thin layers of material by bombarding a target with accelerated ions in the presence of a magnetic field parallel to the path of the accelerated ions and including apparatus to carry out the method. A voltage is applied to glow discharge electrodes in a vacuum environment causing plasma formation between the electrodes and accelerating the resultant ions toward a target to be etched. A magnetic field parallel to the accelerating electric field is provided to condense the ionic stream and cause more ions to strike the target. Some form of masking is utilized to define the desired pattern of holes in the surface layer of the target.

1 Claim, 4 Drawing Figures





INVENTOR.

Richard E. Quinn

BY

Glen A. Bernstein

ATTORNEY

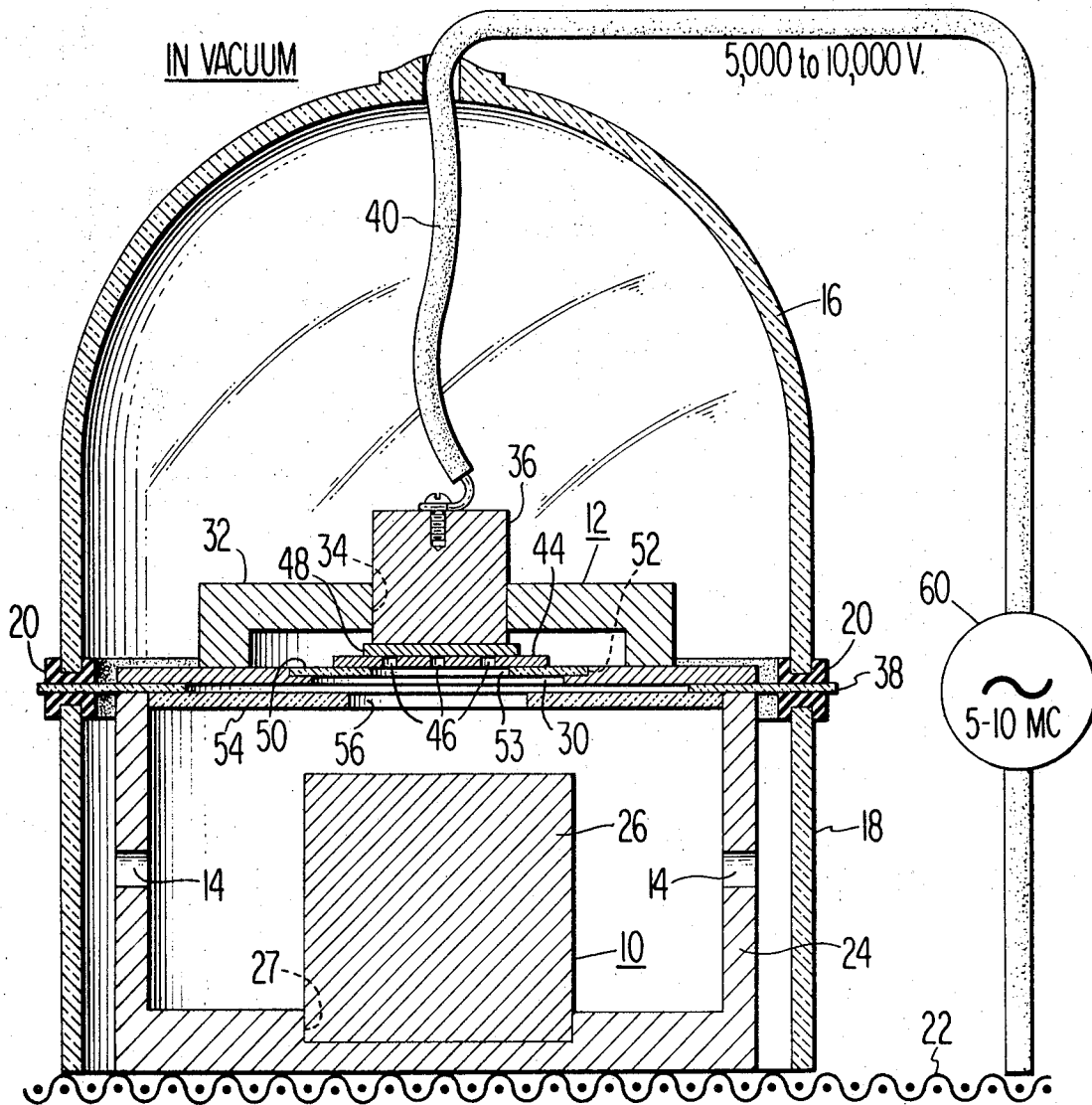


Fig. 2.

INVENTOR.

Richard E. Quinn

BY

Henry H. Bennett

ATTORNEY

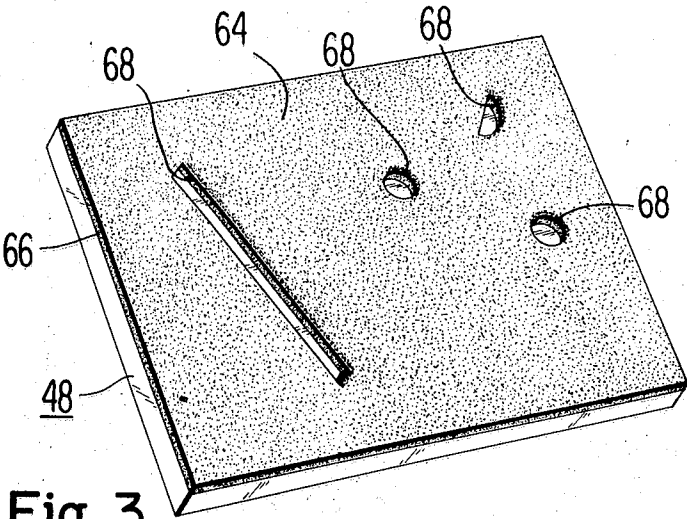


Fig. 3.

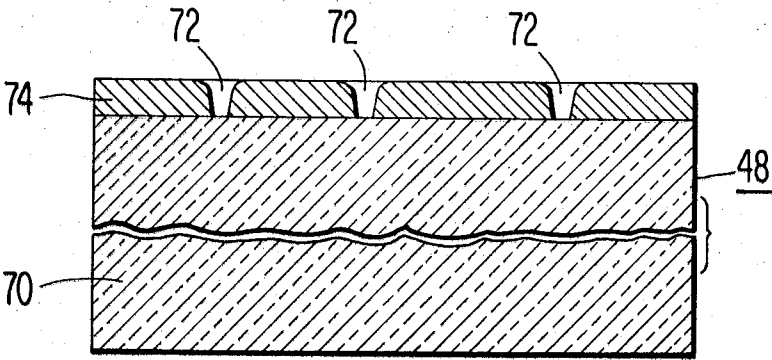


Fig. 4.

INVENTOR.
Richard E. Quinn
BY *Hernando B. ...*
ATTORNEY

APPARATUS FOR ETCHING OF THIN LAYERS OF MATERIAL BY ION BOMBARDMENT

This application is a continuation-in-part of an application filed Jan. 31, 1967, Ser. No. 612,908, now abandoned, which is assigned to the assignee of the instant invention.

BACKGROUND OF THE INVENTION

This invention relates in general to improved methods of, and means for, etching thin layers of material supported on a substrate. It relates particularly to improved methods of and means for etching thin film devices such as thin film polycrystalline or single crystal semi-conductor devices, including active and inactive circuit components, or assemblies thereof, such as thin film transistors and integrated circuits.

Often it is desirable to remove selected areas of a thin film surface during the fabrication of various devices. One method of accomplishing thin film removal is to bombard a surface with ions. This method, used in cleaning operations, requires a source of ions and a means for accelerating them toward the surface to be cleaned. Selective removal of small areas of a thin film is difficult to obtain using this technique.

Ion bombardment can be used to obtain selective removal if an apertured mask is placed between the target and the ion source. This will not solve the whole problem, however, because the ions are too diffused to provide high pattern resolution. Some ions near the mask edge will cut in under the mask, causing the pattern to become blurred. This will be an even greater problem if the thin film device is not completely flat, since gaps will then exist between the mask and the target surface allowing the ions to undercut the mask to a greater extent.

The use of a magnetic field parallel to the accelerating electric field in an ion bombardment apparatus, has been reported by E. Kay, in *J. of Applied Physics*, vol. 34, No. 4 (Part I), April, 1963, pp. 760-768, at page 761. This magnetic field produces a "magnetic wall" which prevent ions from reaching the container wall, which would otherwise cause contamination of the ions and recombinations deleterious to some types of target substrates.

Electron bombardment can be used to remove surface areas of material and to define holes in various materials; but because electrons have little mass, they require acceleration voltages which are about one hundred times higher than those required for ions, and also require the use of a better vacuum. These additional requirements greatly increase the cost of building electron film removal apparatus, without providing practical advantages in many cases.

The photoresist process uses chemical means to remove a thin film. First a layer of polymer is placed over the thin film. Then it is removed from those areas of the thin film which are to be eliminated. Finally the surface is treated with an etchant which eats away the film in those areas not protected by the polymer. Some thin films, such as the oxides of tin, aluminum, and chromium, which form thin films on many electronic circuit devices, are resistant to all but the strongest acids. If films of these materials are as thick as one to two microns, acid must be used for extended periods of time to obtain satisfactory results. Before complete removal can be accomplished in these cases, the acids

may get beneath the protective polymer, enlarge or undercut the holes, and greatly decrease resolution.

Frequently the substrate of the device should be preserved from removal, since the substrate can provide a means of establishing electrical contact with the device. This preservation is possible if the removal can be halted before the substrate is damaged.

When other steps in the fabrication of a thin film device are performed in a vacuum system, it would be quite useful to be able to accomplish the pattern definition step without removing the device from the vacuum. An efficient vacuum etching process would save both time and money. Some substrate materials are prone to rapid oxidation so that after a thin film of oxide has been removed there is often insufficient time to perform necessary operations on the device before a further thin film of oxide forms. Any method of thin film removal in air is subject to this problem, which can best be solved by vacuum removal of desired surface areas coupled with a method of plating or otherwise applying contacts into the newly defined holes while maintaining the vacuum.

SUMMARY OF THE INVENTION

A typical embodiment of the invention includes glow discharge electrodes mounted in a vacuum chamber. A plasma is generated between the glow discharge electrodes by a potential difference which accelerates the random ions present causing collisions and further ion formation. In general, ions may be produced in any manner and accelerated toward the target by any type of electric field. Permanent magnets, electromagnets or a combination of the two are located so that they generate a magnetic field having lines of force parallel to the accelerating electric field. A target thin film device is placed between an apertured mask and the negative accelerating electrode and is, if possible, in electrical and physical contact with both the mask and the electrode. The mask, apertured to provide a desired circuit configuration, is situated between the thin film device and the ionic source.

In another embodiment of the invention a high frequency alternating voltage is applied across the discharge electrodes causing a radio frequency discharge to occur in the space between the electrodes, thus generating an ionic plasma. This embodiment is useful for pattern definition in insulating materials, since a target of insulating material prevents current flow and plasma formation when a direct potential is placed across the electrodes.

Whether alternating or direct potential is used, it is possible to pulse the ion accelerating voltage rather than operate it continuously. This slows down the surface removal rate, but can be advisable if the electrodes overheat.

By using a magnetic field having lines of force parallel to the electric field that accelerates the ion, the invention obtains high pattern resolution in the target. This technique condenses the ionic stream so that more of the ions strike the target causing faster film removal and improving the efficiency of the apparatus. Use of a mask permits selective removal of small areas of a target surface and this is especially important for the fabrication of electronic circuits and devices. The presence of the parallel magnetic field also decreases the proba-

bility of ions undercutting the mask edge and blurring the target pattern.

Most thin film material, including those which are difficult to remove by the photoresist process, can be etched by this invention. Masking allows areas of the target surface to be protected during the film removal process even if an extended period of bombardment is required for complete film removal. Areas of the target substrate can be preserved by masking the substrate with a thin film of a material which is resistant to ion bombardment. The substrate can provide a means of establishing electrical contact with the target device and the invention provides an easy, inexpensive method of protecting it.

Because the ion bombardment etching occurs in a vacuum, it can be easily integrated with other steps in the fabrication of a thin film device since many of these steps also require a vacuum environment. This will avoid the expense and problems involved in removing the target from the vacuum for the etching step. Material can be sputtered onto the target surface as well as removed from it while the target remains in the apparatus. After a pattern of apertures has been defined in the target, material is plated or sputtered onto target surface through the mask without disturbing the vacuum by reversing the polarity of the ion accelerating electric field.

THE DRAWINGS

The invention will be described in greater detail by reference to the accompanying drawings in which:

FIG. 1 is an elevational view of a typical structure for carrying out the invention;

FIG. 2 is an elevational view of a structure for carrying out the invention including an external source of high frequency alternating voltage;

FIG. 3 is a perspective view of an electric circuit device which has been selectively plated with a thin film of a material which is resistant to the effects of ion bombardment; and

FIG. 4 is a side view of an electric circuit device in which the substrate is fabricated of a material that is resistant to the effects of ion bombardment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, the entire apparatus is mounted in a vacuum chamber which is not shown but is indicated by legend. Hoses connected to the chamber evacuate the apparatus until the pressure is low enough to permit plasma formation in the area between the electrodes 10, 12. The chamber communicates with this area through gas ports 14.

A two piece glow discharge containment arrangement 16, 18 provides electrical isolation for the system. The domed portion 16 can be removed to allow access to interior parts. Gaskets 20, also of insulating material, separate the two halves of the glow discharge chamber. A wire mesh screen 22 at anode potential supports the apparatus.

The electrical circuit includes the two glow discharge electrodes 10, 12. The positive electrode or anode 10 includes an anode cup 24 and magnet 26 which is mounted in a depression 27 centrally disposed within the cup 24. The negative electrode 12 includes a circu-

lar cathode plate 28 having a centrally disposed circular aperture 30, a rectangular iron bar 32 bent at the ends to form legs which rest on the cathode plate 28 and having a centrally disposed circular aperture 34, and a soft iron slug 36 which fits within the circular aperture 34 of the bar 32. The cathode plate 28 rests on a circular piece of insulating material 38 which physically separates the anode and cathode and provides isolation between them. One terminal of an external direct voltage generator is connected to the cathode 12 at slug 36 through insulated lead 40 and the other terminal is connected to wire mesh screen 22 which is at anode potential.

The magnetic circuit includes a magnet 26 which is mounted in a depression 27 centrally disposed within the anode cup 24 and may be either a permanent iron magnet or an electromagnet. The iron bar 32 provides a return path for the magnetic lines of force. The soft iron slug 36, mounted in the circular aperture 34 at the center of the iron bar 32, completes the magnetic circuit.

In the embodiment of the invention shown in FIG. 1, a mask 44 is provided, comprising a thin sheet of material having a pattern of apertures 46 to etch a desired pattern of holes in a target 48. The mask 44 has a surface of a material such as nichrome which is resistant to the effects of ion bombardment. The mask 44 is spaced with respect to the cathode plate 28 coaxially with the cathode plate aperture 30 by a spacer 50 mounted in a centrally disposed depression 52 in the cathode plate 28 and has a circular centrally located aperture 53 which is directly beneath the target area coaxial with apertures 30 and 34.

The spacer 50 preferably comprises a non-magnetic metal, such as aluminum or iron. The use of a metallic spacer insures that the mask 44 is maintained in electrical contact with the cathode 12 for all types of targets. The target 48, in which a pattern of holes is to be etched, is sandwiched between the soft iron slug 36 of the cathode 12 and the apertured mask 44; the target 48 should be in physical contact with both the slug and the mask.

A circular shield 54 of insulating material may be placed beneath the cathode 12. The shield 54 has a circular centrally located aperture 56 which has a slightly larger area than the target 48 and is directly beneath the target area coaxial with apertures 30, 34 and 53. To be effective, this shielding should be placed close to the cathode plate 28.

After holes have been etched in the target 48, the electrical polarity of the apparatus can be reversed (the cathode 12 becomes the anode and the anode 10 becomes the cathode) and material from the surface of the anode 10 may be sputtered onto the exposed areas of the target 48 through the apertures 46 in the mask 44. To accomplish this sputtering step, the magnet 26 has on its flat surface, facing mask 44, a layer of sputterable material 58.

FIG. 2 illustrates another embodiment of the invention. A high frequency alternating voltage generator 60 is connected to the cathode slug 36 through the insulated lead 40 and to the wire mesh screen 22 which is electrically connected to the cup 24. In this apparatus an ionic plasma is developed by radio frequency discharge in the area between the electrodes 10, 12.

This arrangement may be used if the target 48 is an insulating material.

FIG. 3 illustrates an alternate method of masking selected areas of the target 48. Areas 64 of the surface of the target 48 facing the beam of ions, which areas are to be protected from the effects of ion bombardment, are coated with a thin film 66 of a material such as nichrome which is resistant to ion bombardment. The areas 68 to be removed are left uncoated. In such an embodiment, the separate mask 44 of FIG. 1 may be omitted. This type of masking may be used when the target 48 does not present a planar surface to the bombarding ions, since then the separate mask 44 is not readily placed in contact with the surface of the target and ions would tend to undercut the mask and blur the hole pattern, if the separate mask were used.

FIG. 4 illustrates target 48 having a substrate 70 fabricated of a material that is resistant to ion bombardment. When holes, such as 72, are produced in a surface thin film 74 by ion bombardment in the arrangement of FIG. 1, the substrate 70, being resistant to the ion bombardment, is not affected, even at the areas exposed by the holes 72.

In the embodiment of the invention shown in FIG. 1, a potential difference between the electrodes 10, 12 with the anode positive, causes the random ions present to be accelerated and to collide with nearby atoms producing further ionization and plasma formation. The resultant electric field causes positive ions to be accelerated toward the slug 36 of the negative electrode 12 so that a current flows across the air gap between the magnet 26 and the slug 36. The target 48 is located at the center of the slug 36 where it is struck by the maximum number of accelerated ions. The mask 44 limits removal of target material to those areas of the target 48 exposed by the pattern of apertures 46 in the mask 44. By changing masks, different patterns of holes and slits can be etched in the target 48. To insure sharp pattern definition, the mask 44 should be in physical contact with all points of the target surface facing the bombarding ions, otherwise some ions may undercut the mask edge and blur the target pattern. Further, by maintaining the mask 44 in electrical contact with the cathode 12, as previously described, the interaction between the electrical (E) and magnetic (H) crossed-fields at the edge of the aperture 46 of the mask directs ions at the edge parallel to that edge, rather than underneath it. Thus, the likelihood of mask undercutting is greatly reduced.

By orienting the magnet 26 and the slug 36 as shown in FIG. 1, a magnetic field is generated having lines of force parallel to the accelerating electric field produced by electrodes 10, 12. Electrons present in the plasma tend to follow the magnetic field lines and are confined in a column between the electrodes 10, 12 having approximately the transverse cross-sectional area of the magnet 26 and the slug 36. Plasma density is thereby increased, and since the target 48 is located within this column, a greater number of ions strike its exposed areas providing high efficiency. The presence of this magnetic field also decreases the number of ions which tend to undercut the edge of the mask 44 and which may cause the target pattern to become blurred, because ions tend to follow paths parallel to the magnetic field.

The apertured shield 54 of insulating material is placed between the electrodes 10, 12 to improve efficiency. The shield 54 effectively shields most of the area of the cathode 12 causing the ionic current to flow through the aperture 56 at the center of the shield 54 which is located directly beneath the target 48 and mask 44. The aperture 56 is slightly larger than the area of the target 48 to insure uniform bombardment across the whole target area. In order to be effective, the insulating sheet 54 should be placed close to the cathode plate 28 so that the ionic stream will not diverge before striking the target 48. Mask support 50 adds further cathode shielding.

In the embodiment of the invention shown in FIG. 2, the ionic plasma is produced by a radio frequency discharge occurring in the area between the electrodes 10, 12. The radio frequency discharge occurs when a high frequency voltage generator 60 is connected to the electrodes 10, 12. The alternating voltage generator 60 of FIG. 2 produces a voltage of 5,000 to 10,000 volts within a range of frequencies from 5 to 10 megacycles.

Ion bombardment will provide pattern definition in most metal, insulating, and semiconducting materials including those which are difficult to etch by the photoresist process. Some metals such as aluminum, nichrome and chromium are not greatly affected by ion bombardment, but are useful for masking target areas. Removal rates for most materials are approximately 12 angstrom units per second using the following example parameters: flux density of 1,000 gauss over a $\frac{3}{4}$ inch air gap, a pressure of 0.3mm of mercury, and an anode cathode voltage drop of 800 volts with a current density of 5 ma/cm². Increased removal rates can be achieved by utilizing ions, such as fluorine, which react chemically with the target to provide both ballistic and chemical action to remove the target material.

The apparatus of FIG. 1 was used to cut a slot in a gold film 300 angstroms thick deposited on glass. A regular sputtering mask 48 with a thin coating of rhodium to protect it from the bombarding ions was used to define the slot. Any suitable material which resists ion bombardment such as those mentioned above could have been used to protect the mask surface. Removal took place through the mask 48 having an aperture 0.008 inch wide. A pressure of 0.2mm of mercury was maintained in the apparatus. Bombardment for 75 seconds was required for complete film removal. The slot produced was the same width as the mask aperture with well-defined edges. The results were comparable with those obtainable by chemical means.

The method and apparatus described offers the advantage of potential savings in time and expense because much of the work of fabricating thin film devices occurs in a vacuum and etching the thin film by the means described herein is readily accomplished without removing the device from the vacuum, thereby eliminating the handling involved in other methods. Since this process does not take place in the atmosphere, the reoxidation problems encountered when some substrate, such as silicon, are exposed to air, are greatly reduced.

By reversing the polarity of the accelerating electrical field in the apparatus of FIG. 1, contacts can be sputtered into the newly defined holes allowing a

completed device to be made in a vacuum. The top of the magnet 26 is coated with sputterable material 58 as shown in FIG. 1. When the electrical polarity of the apparatus is reversed, the material of the magnet coating 58 is deposited on the exposed areas of the target 48 5 through the mask apertures 46. To accomplish this sputtering step, the electrical spacing preferably is decreased, but this can be done by an external control.

I claim:

1. Apparatus for etching a surface of a target, comprising, in a vacuum: 10

- a. upper and lower insulating housings each having an opening which communicates with the other opening;
- b. an insulating gasket between said housings; 15
- c. an insulating member extending through said gasket and into said openings, said member having a central aperture therein;
- d. a first electrode disposed in said upper housing 20

and comprising

- a metallic plate having a central aperture therein, said plate being carried by said insulating member,
- an iron bar having legs carried by said plate, and an iron slug centrally disposed in said iron bar;
- e. a non-magnetic conductive spacer having a central aperture, disposed in said upper housing and carried by said plate;
- f. an apertured mask centrally disposed in said upper housing and carried by said spacer
- g. said target interposed between said mask and said iron slug; and
- h. a second electrode in said lower housing and comprising a metallic cup and a magnet centrally disposed in said cup, said magnet being in alignment with said iron slug, said target, said mask, and said central apertures.

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