Sept. 6, 1966 M. P. LEPSELTER 3,271,286

SELECTIVE REMOVAL OF MATERIAL USING CATHODIC SPUTTERING

Filed Feb. 25, 1964 2 Sheets-Sheet 1

FIG. 1

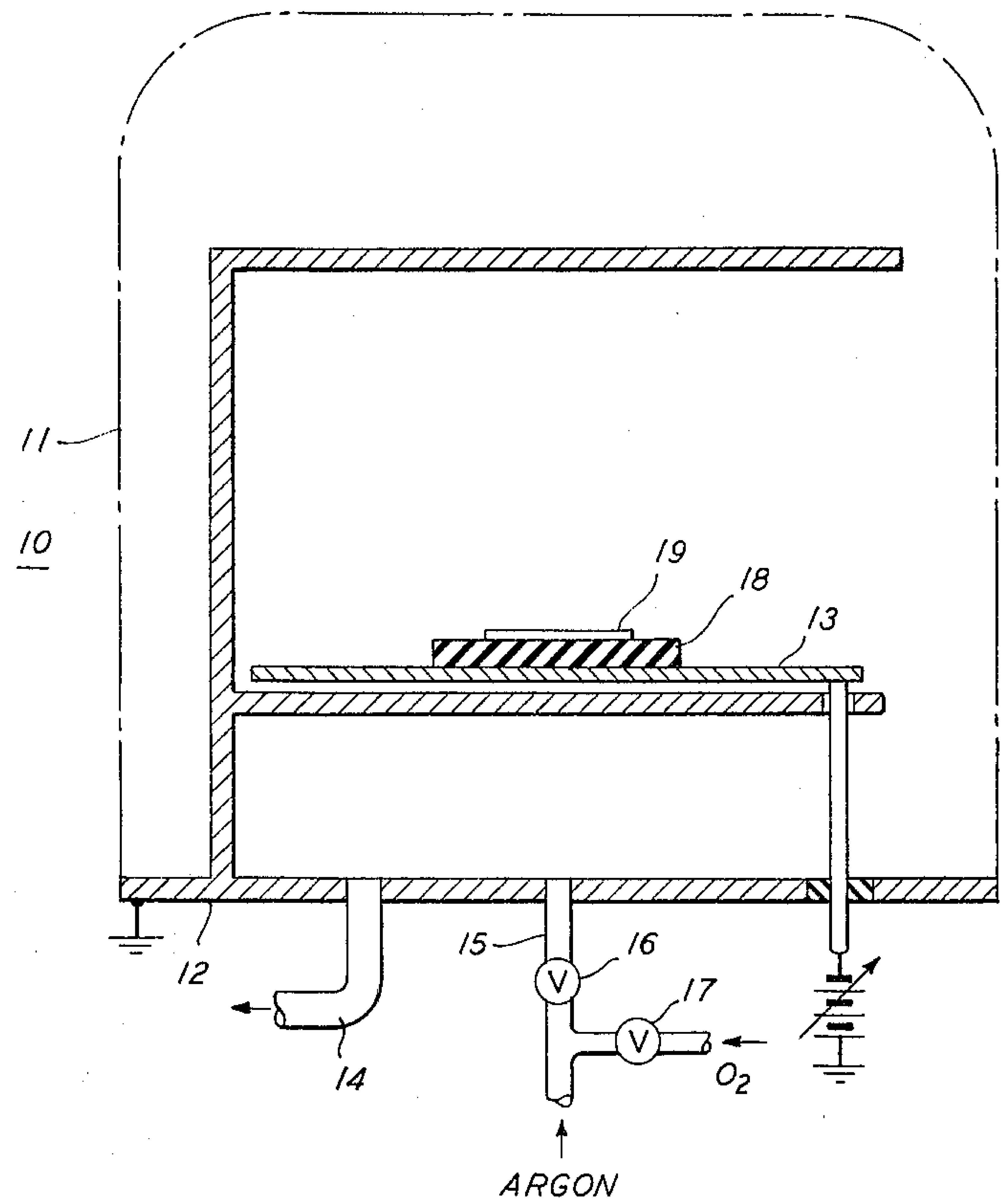

FIG. 2

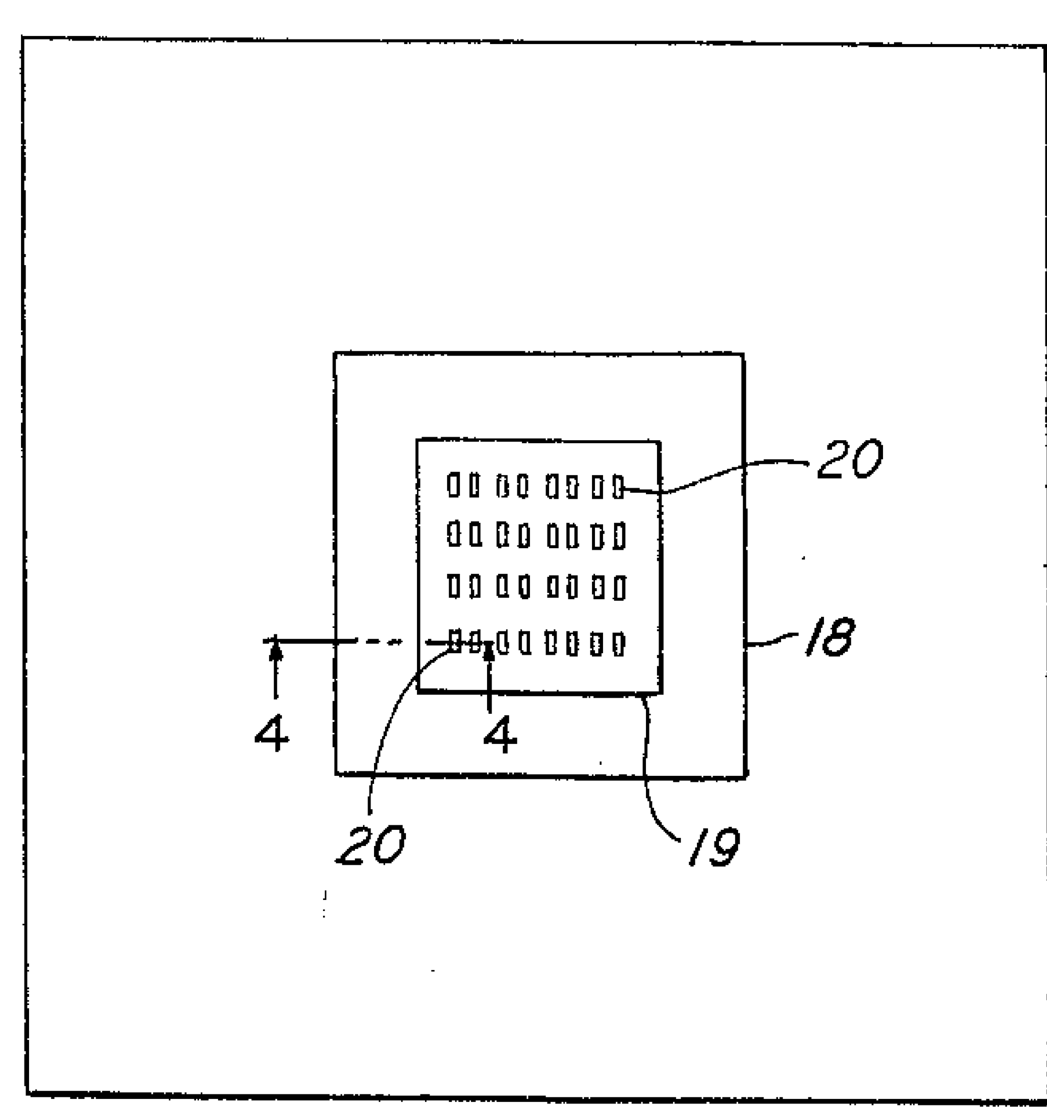

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FIG. 3

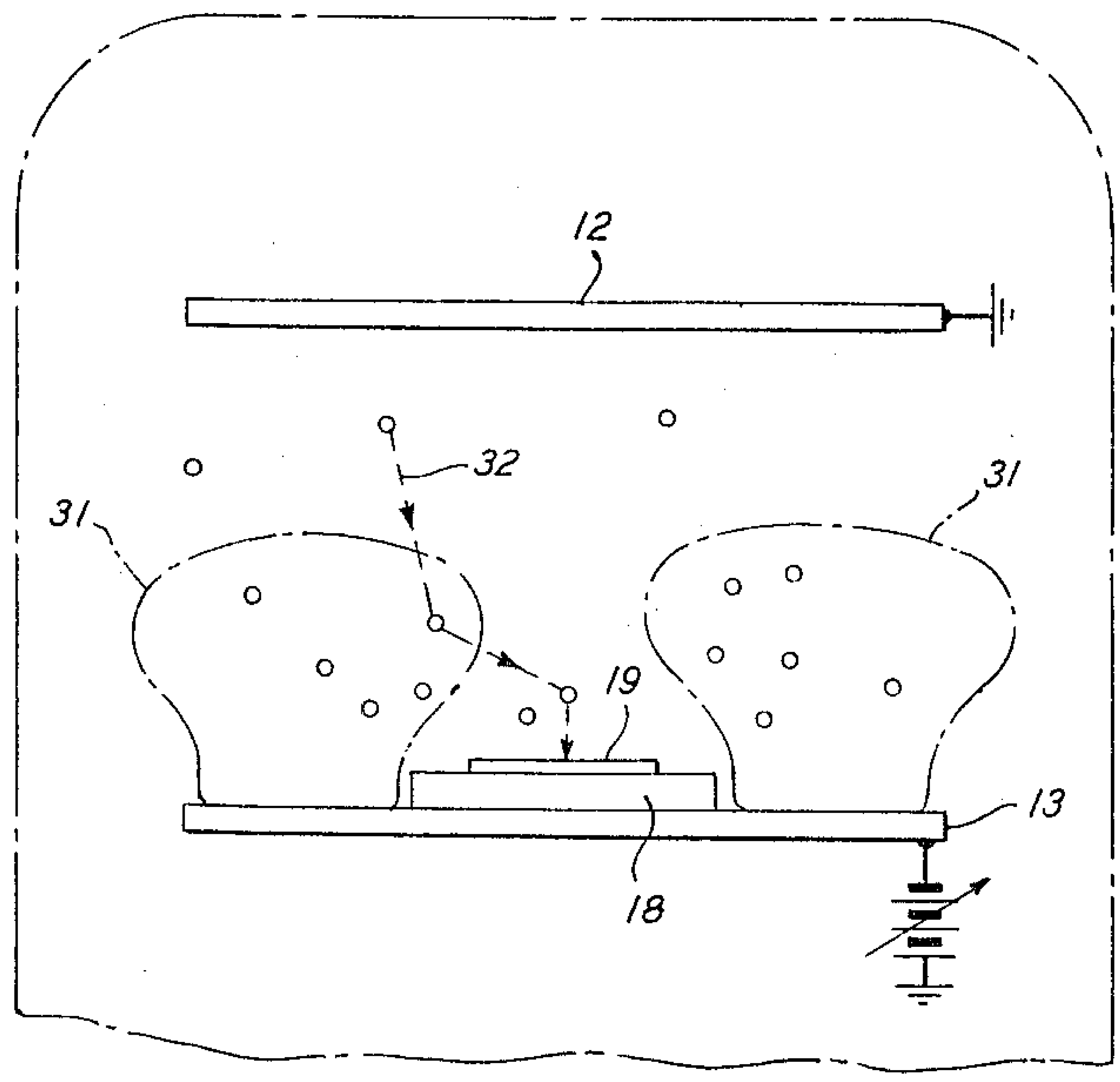
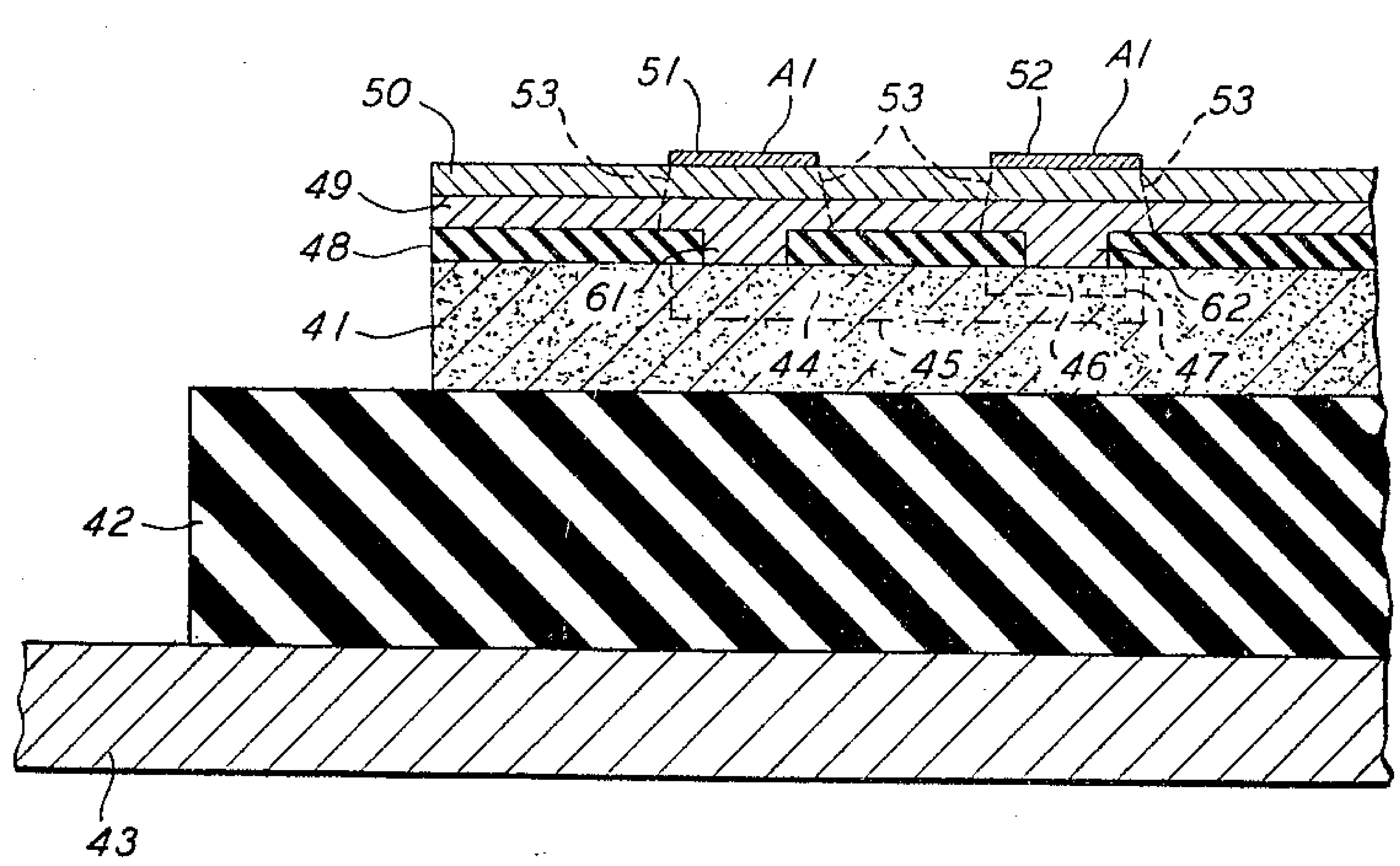

12
32
31
31
19
13
18

FIG. 4


50
53
51
Al
53
52
Al
53
49
48
41
61
62
44
45
46
47
42
43

3,271,286

SELECTIVE REMOVAL OF MATERIAL USING CATHODIC SPUTTERING

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Filed Feb. 25, 1964, Ser. No. 347,173
2 Claims. (Cl. 204—192)

This application is a continuation-in-part of my application Serial No. 331,168, filed December 17, 1963, wherein a technique is disclosed for the selective removal of material from the surface of a semiconductive member by what has been termed "back-sputtering."

This invention relates to a method for selective removal of material from a workpiece by cathodic sputtering. In particular, the method of this invention is useful for selectively removing material from a workpiece which cannot be subjected to the high potentials usually applied to the cathode member in the sputtering process.

In connection with the cathode sputtering process, it it known that the surfaces of materials may be cleaned or, in effect, etched by means of the sputtering process inasmuch as the cathode member itself is eroded by the bombardment which is basic to sputtering. It is apparent that a form of cleaning occurs as a consequence of the removal of surface layers. However, the application of the cathode sputtering technique to remove layers from the surface of semiconductor bodies using potentials of the order of three to ten kilovolts across the cathode member is likely to cause permanent damage to the semiconductor body. This damage is particularly significant in the case of oxide-protected semiconductor bodies inasmuch as high electric fields cause permanent breakdown of the dielectric coatings.

Accordingly, an object of this invention is an arrangement for selectively removing material from the surface of a workpiece without directly applying high voltages across the workpiece.

More specifically, an object of the invention is a back-sputtering technique for effecting selective removal of portions of surface coatings on a semiconductor surface which includes dielectric oxide films.

In accordance with this invention, the workpiece is separated from the cathode member by an insulating layer and the cathode is so shielded as to result in the formation of a glow dischage region around the periphery of the semiconductor workpiece. Typically, the glow discharge region may be in the form of an annular ring or a rectilinear loop or annulus. This glow discharge region tends to spread somewhat with distance away from the cathode surface and, accordingly, tends to fill up some of the central volume directly over the workpiece.

The result of the formation of a cathode glow discharge in this pattern is to cause the gas ions, which are produced within the vacuum chamber of the sputtering apparatus, to move into the glow discharge region, gain energy and move out by the collision process to the space above the workpiece, and thence by further collision with other ions to impact substantially normally upon the surface of the workpiece. As is known, it is this ion impact which apparently products the sputtering action and material removal from the impacted surface. Thus, the semiconductor workpiece surface is bombarded without applying directly across the semiconductor member the high voltage field which exists across the cathode member for producing the glow discharge region.

Inasmuch as the ions impact substantially normally on the workpiece surface, the material removal tends to occur in a very precise manner with a practically straightsided cutting action along the boundaries of the differentially

coated surface. In this connection, the invention is applicable to any differentially coated surface. By this is meant a surface which either has layers of differing thickness of the same material over different portions of the surface or in which different portions of the surface have coatings of different materials each having different sputtering efficiencies. In the former case where the same material is used but with heavier layers over some portions, the material will be removed by sputtering to a substantially equal depth over the entire surface but will, of course, disappear completely from the more thinly coated areas first. In the latter case where different materials are used, one material which sputters less efficiently, and thus more slowly, than the others may constitute a mask to preserve portions underlying the mask while other portions are eroded and removed.

The invention and its other objects and features will be more clearly understood from the following detailed explanation taken in connection with the drawing in which:

FIG. 1 shows in schematic form apparatus suitable for the practice of the invention;

FIG. 2 is a plan view of the cathode member, the workpiece and the interposed insulating and shielding member,

FIG. 3 is a schematic representation of a portion of the apparatus depicting outlines in cross section of the glow discharge region in accordance with this invention; and

FIG. 4 is a partial cross section of the semiconductor workpiece, the underlying portion of the insulating member and a portion of the supporting cathode member.

Referring to FIG. 1, there is shown in schematic form a vacuum enclosure **10** represented by the broken line **11**. Within the chamber and forming the base thereof is an anode member **12** which is held at ground potential. Shieldingly supported within the enclosure is a cathode member **13** to which a D.-C. supply is connected for applying relatively high negative potentials of the order of from three to ten kilovolts. Schematically shown penetrating the base of the chamber are connections **14** for evacuating the chamber by conventional means such as diffusion pumps, and an inlet connection **15** with suitable stop valves **16** and **17**. As represented by the inlet arrows, the main supply line may be connected to a source of argon gas and the auxiliary line controlled by stop valve **17** to an oxygen supply for providing protective oxide coatings, as will be explained more fully hereinafter.

As shown in FIG. 2, centrally placed on the cathode **13** is a similarly shaped ceramic member **18**, and centrally mounted on ceramic member **18** is a semiconductor workpiece **19**.

A pattern of deposited metallic electrodes in the form of stripes **20** are shown on the surface of the semiconductor workpiece. This pattern is primarily for exemplary purposes, and it will be understood that a variety of metal patterns may be used with this invention. The relationship of these stripes **20** to the other parts of the device structure are illustrated in more detail in the partial cross section shown in FIG. 4. In FIG. 4 the semiconductor workpiece portion **41** contains a series of three conductivity type regions making, for example, a transistor. In addition to the original bulk portion of the silicon **41**, there is shown a base region **44** defined by the pn junction **45** and an emitter region **46** defined by the second diffused pn junction **47**. On the surface of the silicon slice is a layer **48** of silicon oxide through which openings **61** and **62** have been made to expose surface portions of the base and emitter regions **44** and **46**, respectively.

Ohmic contact is made initially to the silicon by depositing platinum over the entire oxide layer and heating the material to about 600 degrees centigrade. As disclosed in the aforementioned application of Lepselter, this causes a solid phase reaction akin to alloying between the platinum and the silicon. The platinum on the oxide surface, which is uncombined, then is readily removed by treating the surface with aqua regia. Solutions stronger than the usual three parts hydrochloric acid to one part nitric acid may be used to hasten the speed of platinum removal. This technique has the advantage of leaving the alloyed platinum unaffected.

Following this a layer **49** of titanium is deposited so as to overlie the oxide layer **48** and to make contact to the alloyed surface regions. On top of the titanium layer is a second layer **50** of platinum. Finally, on top of the platinum layer a thin layer of aluminum is deposited. By means of a photoresist technique the aluminum plating is removed, using a suitable etchant, except for the stripe electrodes **51** and **52** which are in registration with the openings to the base and emitter regions. Inasmuch as the aluminum layer is relatively thin, of the order of several hundred angstroms, chemical etching produces a precise pattern delineation.

An alternative to the formation of these aluminum stripes is the formation of similar gold stripes which are of much greater thickness. Such gold stripes are readily produced to a precise pattern by depositing the gold on a photoresist pattern which defines the stripe area as uncoated portions of the surface. The gold deposited stripes may be built up to considerable thickness so as to provide a differentially coated surface. Thus, as described hereinafter, although the aluminum has poor sputtering efficiency and thus is not attacked substantially, the gold will be sputtered but because of its greater thickness will persist after all of the platinum and titanium have been removed.

To complete the fabrication of the electrode structure of the device in the semiconductor workpiece, the first and second metal layers, namely titanium and platinum, must be removed from the workpiece surface except where these layers underlie the aluminum stripe electrodes **51** and **52**. In accordance with this invention, this removal is conveniently done by the process of back-sputtering. This technique is particularly valuable where the spacing between the electrodes **51** and **52** is in the order of microns.

As shown in the cross sectional view of FIG. 4, the method of the invention requires an aluminum cathode number **43** upon which the semiconductor workpiece is mounted using an intermediate ceramic insulator **42**.

An understanding of the uniqueness of the arrangement in accordance with this invention may be had from a description of the use of the apparatus. The conditions employed in cathodic sputtering are known (see "Vacuum Deposition of Thin Films," L. Holland, J. Wiley & Sons, Inc., New York, 1956). In this process a known reactive gas such as, for example, hydrogen or any of the members of the rare gas family such as helium, argon or neon is introduced into the chamber. As set forth in the above text by Holland, the cathode sputtering system may be operated statically by providing a fixed pressure of gas in the system, or dynamically such that a fixed gas pressure is maintained with a constant flow of gas through the system.

In operation, the apparatus of FIG. 1 is subjected to a pressure of approximately ten microns of argon gas, and with the anode **12** at ground potential a negative voltage of five kilovolts is applied to the cathode. Under these conditions, as shown in FIG. 3, a glow discharge region having a cross section substantially as depicted by the broken outlines **31** is produced around the periphery of the ceramic member **18**. This glow discharge region is annular in form and surrounds the workpiece on all sides, and extends, to some extent, over the space above the workpiece **19**. This glow discharge region **31** represents primarily the cathode discharge region and is the source of energy for particles passing through or located within the region. Under the conditions described, argon gas ions are produced within the vacuum chamber. As these particles move about, they collide and some are propelled into the glow discharge region where they gain energy and, by further collision, travel into the space above the workpiece and from thence into impact with the workpiece surface. One possible path is depicted by the arrowed broken line **32** connecting the circles representing gas particles in FIG. 3. It has been found that with the configuration shown, the bulk of the bombarding particles impact the workpiece surface substantially normally and consequently the "cutting" action of the sputtering process produces straight-sided structures as represented by the broken lines **53** of FIG. 4. As shown in this same figure, the masking effect of the aluminum electrodes **51** and **52** combined with this sputtering process result in very sharply delineated patterns on the semiconductor workpiece surface.

The process described above in connection with this invention is most advantageous when compared with ordinary chemical etching techniques in which the eroding action proceeds at a differential rate as the etching depth increases. This tends to produce either undercutting or slope-sided cross sections rather than precise rectilinear cross sections. The value of the back-sputtering technique is particularly notable where the unmasked area has a width of the order of one-half mil or less. For such configurations, the use of chemical etching to depths of greater than several thousand angstroms is a practical impossibility insofar as applicant is aware.

The effectiveness of the arrangement described herein for back-sputtering material from a semiconductor surface on which a protective oxide coating has been placed will be recognized from the effect produced if the high cathode potential is applied across the workpiece itself. If, for example, the silicon oxide coating is about 5000 angstroms thick and the applied voltage is five kilovolts, both of which are typical values, than the field applied to the dielectric oxide is about 10^8 volts per centimeter. This assumes that, as is the fact, most of the voltage drop occurs across the oxide layer. Inasmuch as the breakdown voltage for relatively high quality dielectric oxides is about 10^7 volts per centimeter, the result of such high applied fields tends to be pin-hole breaks through the oxide coating which, of course, effectively destroy the coating as a protective layer. In accordance with this invention, such consequences are avoided by the arrangement described above.

The foregoing back-sputtering technique for the selective removal of metal may be combined advantageously with known procedures for depositing coatings by cathode sputtering within the same vacuum chamber. In particular, oxide coatings may be produced on the semiconductor workpiece surface at any desired stage in the fabrication process by admitting controlled amounts of oxygen to the inlet lines using stop valve **17** as noted hereinbefore. By the reactive sputtering process well known in the art, oxide coatings of aluminum, for example, where the cathode member is aluminum may be deposited on the semiconductor member. Thus, it will be apparent that surfaces may be built up by deposition of metals, removed in whole or in part, and coated with dielectric layers, in succession using the apparatus as described above.

Moreover, it has been found that even though the devices disclosed in accordance with this invention are not provided with the overlay structure of metal and oxide layers disclosed in the aforementioned Lepselter applicaton, the devices herein have extremely good long-term stability which seems to arise simply as a consequence of the oxide coating having once been covered with metal. In particular, devices of the type disclosed herein where the oxide coating covers p-type conductivity material and where the two layers of metal have been deposited on, and then removed from the oxide surface, there appears to be very complete resistance to the formation of surface channels in this material which generally rendered such devices unusable.

Although the invention has been described in terms of a particular embodiment, it will be understood that other arrangemnts may be made by those skilled in the art which likewise will fall within the scope and spirit of the invention.

For example, other cathode configurations may be employed, even omitting the ceramic spacing member so long as the workpiece is electrically insulated from the cathode and the glow discharge region produced is peripherally disposed and out of contact with the workpiece.

What is claimed is:

1. A method for the selective removal of material from the surface of a substrate having a dielectric coating thereon, comprising effecting a glow discharge in a low pressure gaseous ambient between an anode and a cathode whereby an ionized gaseous plasma is formed in said glow discharge, electrically isolating an area of the surface of said cathode facing said anode larger than the

cross sectional area of said substrate, but having the peripheral portions of said cathode in electrical communication with said discharge, and mounting said substrate between said anode and said electrically isolated area of said cathode so that no voltage drop occurs through said dielectric coating whereby said glow discharge is restricted to the region peripheral to said surface so that ions are impacted on said surface removing material therefrom.

2. The method in accordance with claim **1** in which the substrate is a semiconductor body and the dielectric coating is an oxide layer.

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