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METHOD OF MAKING A WORKPIECE AT A UNIFORM POTENTIAL DURING CATHODE SPUTTERING

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FIG. 1

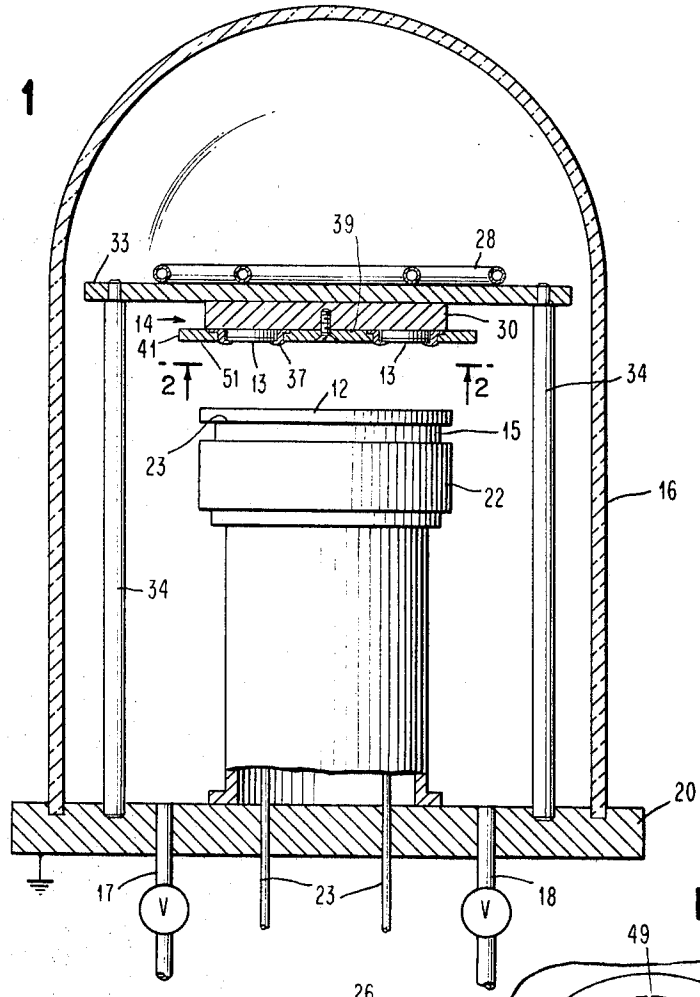


FIG. 2

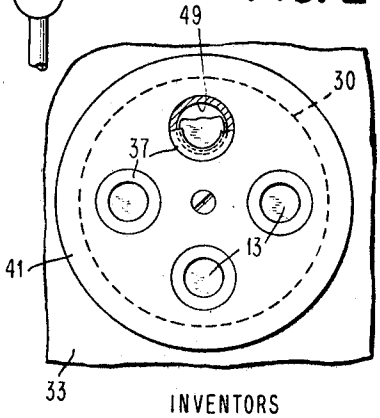
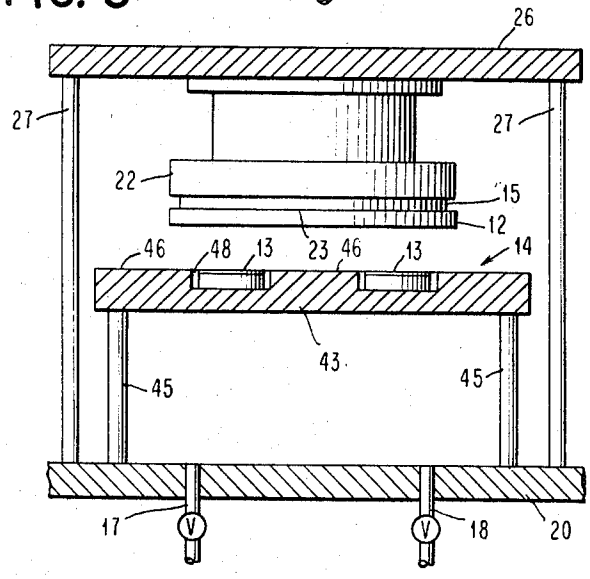


FIG. 3



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METHOD OF MAKING A WORKPIECE AT A UNIFORM POTENTIAL DURING CATHODE SPUTTERING

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This invention relates to apparatus for sputtering material onto a support that is called a substrate. More specifically, this invention relates to an improved anode structure for sputtering apparatus.

In sputtering apparatus of the general type that will be described, a high vacuum gas is ionized between two electrodes, and a target of the material to be sputtered is located in the ionized region where ions bombard the target and dislodge atomic size particles. A substrate is positioned to have the sputtered material deposited on its surface. For sputtering a conductive material, the target can be constructed to function as the cathode electrode. For sputtering a dielectric material such as glass or quartz, the target is positioned between the two electrodes. The substrate is usually mounted on the anode electrode.

OBJECTS

Sputtering is particularly useful in forming very thin films of semiconductor material on a substrate. Complex semiconductor structures can be built by sputtering successive layers of different materials and etching through one or more layers of the material at selected points. For accurate etching, the films must be given very uniform thickness; etching too far where the film is thin or etching only partially through where the film is too thick can ruin a costly semiconductor structure. One object of this invention is to provide a new and improved sputtering apparatus that sputters the target material onto the substrate in films of very uniform thickness.

Since semiconductor structures are often produced in high volume, a sputtering apparatus should be able to deposit the target material on the substrate at a high rate. Another object of this invention is to provide a new sputtering apparatus that deposits material at a significantly improved rate. Another object is to provide a new and improved sputtering apparatus that can handle larger batches of substrates.

The goals of achieving uniform thickness and a high sputtering rate conflict seriously. When the sputtering rate is increased, the sputtered material usually is deposited less uniformly. A feature of this invention is that both of these goals are achieved to an improved extent.

Another object of this invention is to provide a new and improved sputtering apparatus of the type in which the cathode and anode electrodes are energized with a radio frequency (RF) alternating voltage. (By contrast, other sputtering apparatus have been arranged to operate with a direct voltage, with a low frequency alternating voltage, and with an alternating voltage that is biased to have a direct voltage component.) A more specific object is to provide a new and improved anode structure for an RF sputtering apparatus.

INTRODUCTION TO THE INVENTION

From earlier experience with direct voltage energized sputtering apparatus and other types, workers in the sputtering art have believed that the anode structure and position are not significant so long as the anode does not extend into the Crooks dark space, the region near the cathode where the electrical gradient is high and the ions are given the energy that they transfer to the target. This

was observed in prior art apparatus and it was explained in terms of the strlcture of the discharge within the vacuum enclosure: The anode terminal is separated from the dark space by a luminous region called the positive column where the voltage gradient is very low. The known relationship between the anode and cathode terminals and different regions of the discharge is discussed in Holland, Vacuum Deposition of Thin Flms, pp. 80–83.

In the sputtering apparatus of this invention the anode is located very close to the cathode. It has been found that this feature substantially improves the rate at which the target material is deposited on the substrate, but by itself it tends to make the sputtered material form unevenly on the substrate. The sputtering apparatus of this invention further includes a novel anode structure that further improves the rate the sputtered material is deposited on the substrate and also causes the material to be deposited on the substrate in very uniform layers.

According to this invention the anode is constructed to provide a surface that is parallel to the cathode surface and is flush with the substrate surfaces. The anode is also constructed to extend somewhat beyond the edges of the substrate. A probable explanation for the effectiveness of this structure is that some form of capacitive coupling takes place between the RF electrode (cathode) and the anode, resulting in a more efficient use of the RF input power (the inductance between anode and ground is smaller when the capacitance between cathode and anode is larger). Both of these effects increase the sputtering rate and improve the uniformity of the depth of the deposited film.

The quantitative aspects of the electrode spacing and the flatness of the anode and substrate outer surfaces will be discussed in the description of a specific embodiment of the invention.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

THE DRAWINGS

FIG. 1 is a front section of the anode structure of one embodiment of this invention and a somewhat schematic showing of a known sputtering apparatus in which this anode structure is useful.

FIG. 2 is a section 2—2 of the anode structure of FIG. 1 viewed in the direction of the arrows in FIG. 1.

FIG. 3 is a front section of the preferred anode structure of this invention and a partial showing of related components of the sputtering apparatus.

INTRODUCTION TO THE SPUTTERING APPARATUS

FIGS. 1 and 3 show the general features of known sputtering apparatus. A general discussion of this apparatus will be a helpful introduction to the more detailed discussion later on the new anode structure and its relation to the other elements. The structures of FIG. 1 and FIG. 3 differ in that the substrates are positioned above the target in FIG. 1 and are positioned below the target in FIG. 3. Components that have generally the same function will be identified by the same number in this introduction. A more detailed description of the general features of the preferred sputtering apparatus is prepared in the application of Davidse, Ser. No. 428,733 assigned to the assignee of this invention, and now U.S. Patent 3,369,991.

The apparatus of FIGS. 1 and 3 is arranged to sputter material from a target **12** onto substrates **13**. The target and the substrates are positioned between an anode electrode **14** and a cathode electrode **15**. To maintain the region between the electrodes suitable for ionization, components **12, 13, 14** and **15** are mounted in an enclosure **16** that is connectable by means of fittings **17** and

18 to a vacuum and to a source of a suitable ionizable gas, typically argon. Enclosure 16 includes a base 20 that forms an electrical ground and supports the electrode structures.

The cathode structure includes the electrode 15 already introduced and an electrode shield 22. The cathode electrode 15 is connected by a suitable conductor to a source of radio frequency alternating voltage. At a suitable frequency, the difference in mobility between electrons and ions in the ionized region of the apparatus causes the target 12 to initially accumulate more electrons during the half cycle when the cathode is positive than positive ions during the opposite polarity half cycles. The negative charge biases the target so that the target functions as a negative or cathode electrode. The electrode shield 22 is mechanically and electrically connected to the ground potential base 20.

In the apparatus of FIG. 1 the cathode structure is mounted directly on base 20 and the target faces upward. In the apparatus of FIG. 3, the cathode structure is mounted on an upper support 26 that is mounted on base 20 by means of posts 27, and the target faces downward.

The anode structure includes the electrode 14 and suitable means for positioning the substrates to face the target 12 (as will be explained in detail later). The anode structure may also include means to control the temperature of the substrates; FIG. 1 shows a coiled tube 28 for circulating a cooling medium, such as air or water, and an electrically heated element 30. In the apparatus of FIG. 1, the anode structure is mounted on a secondary base 33 that is supported on base 20 by posts 34 and is generally similar to the corresponding structure 26, 27 already described in connection with the cathode structure of FIG. 3. In the structure of FIG. 1, the anode terminal faces downward. Means illustrated as flexible clamps 37 are attached to the outermost surface 39 of the substrate heater structure 30. Elements 37 are shaped to retain the substrates 13 in a heat transferring relationship with anode structure element 30. The anode structure of FIG. 1 also includes an element 41 that will be described later.

In the apparatus of FIG. 3, the anode structure includes an element 43 that may have the temperature control function of element 30 in FIG. 1. Element 43 is electrically and mechanically connected to base 20 by means of conductive posts 45. Element 43 has a substantially flat surface 46 facing upward toward target 12. Recesses 48 are provided in element 43 for appropriately positioning the substrates as will be described later.

THE ANODE STRUCTURE OF FIGS. 1 AND 2

The anode structure of FIGS. 1 and 2 is arranged to establish an equipotential surface and to position the substrates with their outermost surfaces substantially in the plane of the equipotential surface. In the structure of FIG. 1, a ringlike clamp element 37 is arranged to hold the substrate 13 with their outermost surfaces substantially coplanar. Element 41 which was introduced but not explained in the preceding section is a conductive element that is mechanically and electrically mounted on the ground potential structure of elements 28, 30, 33 and 34. Element 41 has cutouts 49 for receiving the substrates and it is arranged with its outermost surface 51 substantially coplanar with the outermost surfaces of the substrates. FIG. 2 shows element 41 arranged to receive four generally circular substrates. One of the substrates and the associated retainer 37 are partially broken away in FIG. 2 to better show the construction of the recess 49. As FIGS. 1 and 2 show, conductive element 41 extends somewhat beyond the region of the substrates.

The anode structure of FIG. 3 is generally similar to the anode structure of FIGS. 1 and 2. However, in the structure of FIG. 3, the anode structure is below the target and the substrates simply rest within the recesses 48 in the temperature control element 43. The substrates are provided with suitable spacers to adjust the substrates to have their outermost surface substantially coplanar with the uppermost surface of element 43.

The equipotential surface that is established by element 41 in FIG. 1 and element 43 in FIG. 3 is preferably parallel to the surface of the target 12 so that the sputtered material is deposited evenly on the substrate. From a more general standpoint, the surface of the substrate and the surface 46 or 51 of the conductive element 41 or 43 are oriented with respect to the surface of the target 12 according to the thickness distribution that is to be achieved in different regions of the substrate.

The accuracy to which the anode surface 46 or 51 is coplanar with the surfaces of the substrates appears to be a function of the length of a dark space in the sputtering apparatus. It has been found that differences of about 1/16" do not adversely affect the sputtering operation when the cathode dark space length is less than ½ in. This relation appears to be approximately true for sputtering apparatus with a different dark space length. In the sputtering appaartus of this invention the anode is located very close to the cathode. A suitable distance has been found to be about twice the length of the dark space.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. In a method of sputtering a uniform deposit on a planar workpiece, including providing a sputtering environment of an ionizable gas, and in said environment, a cathode structure having a substantially planar discharge surface, a workpiece supported on an anode structure having a substantially planar surface positioned substantially parallel to the discharge surface of the cathode structure, and causing a sputtering electrical discharge to be supported between said surfaces by applying radio frequency voltage between said cathode and said anode; the improvement wherein said workpiece is recessed in said anode so that the surfaces of said anode and said workpiece are substantially coplanar and said anode and cathode are in juxtaposed relationship and spaced apart so that said anode surface is near to but not within the dark space of the sputtering discharge, whereby said coplanar workpiece surface and said anode surface are at equal potential.

2. The method according to claim 1 wherein said anode structure is spaced from said cathode structure by about twice the length of the dark space.

3. The methods according to claim 1 wherein said workpiece surface is positioned to be coplanar to said anode surface within 1/16 inch of the distance between said anode and said cathode surface.

4. The method according to claim 1 wherein said anode surface extends beyond said workpiece surface.

5. The method according to claim 1 wherein said sputtering environment includes an upper anode structure and a lower cathode structure, and said workpiece is held on said upper anode structure to present a coplanar surface with said anode structure.

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ROBERT K. MIHALEK, *Primary Examiner.*

U.S. Cl. X.R.

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