Feb. 9, 1971 L. T. LAMONT, JR 3,562,142
R.F. SPUTTER PLATING METHOD AND APPARATUS EMPLOYING CONTROL
OF ION AND ELECTRON BOMBARDMENT OF THE PLATING
Filed Oct. 30, 1968

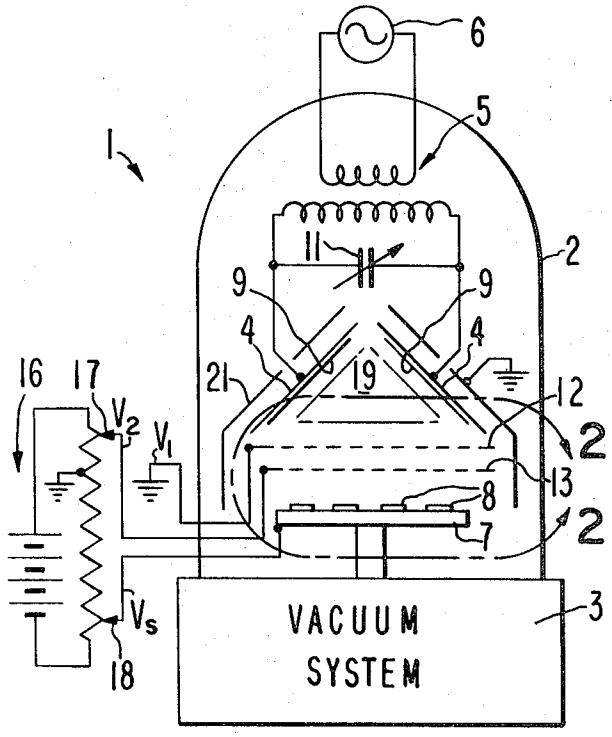


FIG. 1

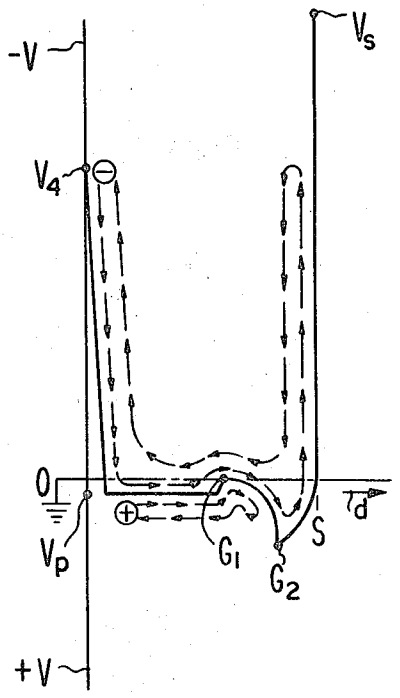


FIG. 3

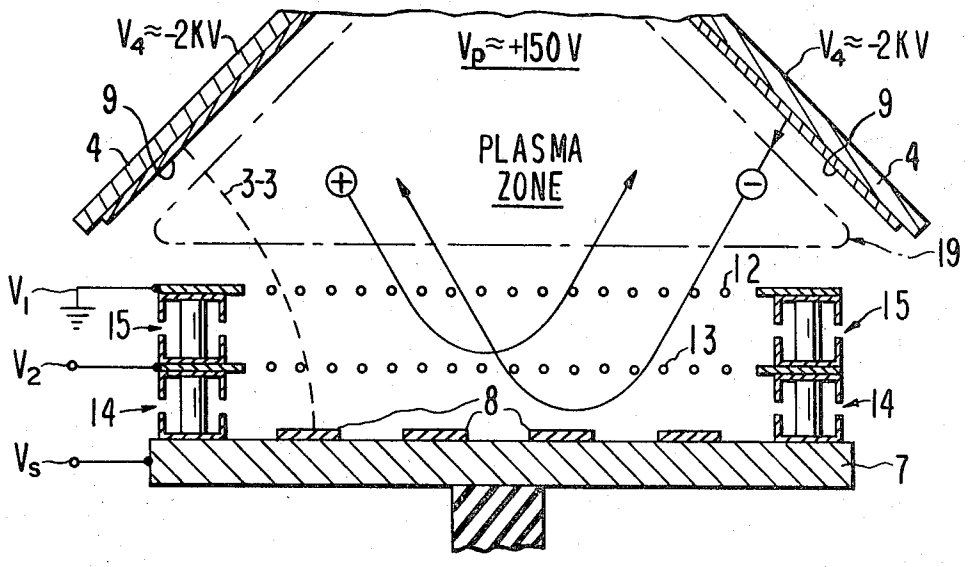


FIG. 2

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United States Patent Office 3,562,142 Patented Feb. 9, 1971

3,562,142

R.F. SPUTTER PLATING METHOD AND APPARATUS EMPLOYING CONTROL OF ION AND ELECTRON BOMBARDMENT OF THE PLATING

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Filed Oct. 30, 1968, Ser. No. 771,797
Int. Cl. C23c 15/00
U.S. Cl. 204—298 3 Claims

ABSTRACT OF THE DISCLOSURE

An R.F. sputter plating method and apparatus is disclosed. The plating apparatus includes a partially evacuated deposition chamber containing a pair of electrodes excited with radio frequency energy to produce a radio frequency plasma discharge in the region therebetween. The R.F. discharge defining electrodes are operated at a floating potential such that, by the nature of the plasma discharge, a relatively high negative self-bias potential is established on the R.F. electrodes. A target material is placed on the R.F. electrodes to be sputtered by ion bombardment, such ions emanating from the plasma discharge. A collector electrode is disposed to receive the sputtered target material to plate the collector electrode or items carried thereon. A pair of transparent grid structures are disposed intermediate the collector electrode and the plasma discharge region. A first one of the grid structures, adjacent the plasma discharge, is operated at ground potential to prevent perturbation of the discharge, whereas the second grid structure disposed intermediate the first grid structure and the collector structure is operated at a potential positive with respect to the discharge for repelling positive ions. The collector structure is operated at a potential negative with respect to the self-bias potential on the target electrodes to repel electrons emanating from the discharge region, whereby ion and electron bombardment of the items being plated is controlled.

DESCRIPTION OF THE PRIOR ART

Heretofore, radio frequency sputter plating apparatus has been employed for plating thin films of material onto devices to be plated. The plating apparatus is typically characterized by provision of a pair of R.F. electrodes in a partially evacuated chamber. The electrodes are excited with radio frequency energy at approximately 13.5 mhz. such electrodes being operated at a floating potential, whereby they self-bias themselves with respect to the potential of the plasma discharge such that they are bombarded by ions originating in the discharge to produce sputtering of the target material carried on the R.F. electrode. The target material is sputtered through the discharge onto a collector structure operated at ground potential such structure also defining one side edge of the plasma discharge. Such an R.F. sputtering apparatus is described in the 14th American Vacuum Society Vacuum Symposium Abstracts published by Herbick and Held Printing Company, Pittsburgh, Pa., 1967, authors, C. F. Lothrop and L. F. Herte.

The problem with the prior art arrangement is that the collector electrode structure was operated at ground potential and was disposed immediately adjacent and defined one side edge of the plasma discharge. As a consequence, high energy secondary electrons produced by ion bombardment of the R.F. target electrodes were caused to bombard the collector structure and the items being plated thereon. Bombardment during the initial stages of film growth greatly improves the adhesion of the film. It

is believed that this is due to the creation of nucleation sites on the substrate either by removal of surface contaminants or by the formation of surface defects. However, continued bombardment during the entire stage of building up the films above a few hundred Angstroms causing the film temperature to be elevated considerably above that of the substrate. This results in a large amount of stress in the surface film which can result in poor adhesion or even flaking. In the case of copper, an additional effect is to reduce the reflectivity of the surface. In the case of depositing aluminum oxide upon a glass substrate, bombardment of the substrate has a deleterious effect upon the glass substrate thereby changing its composition. Therefore, it is desirable to control the electron and ion bombardment of the collector structure and the items being plated thereon at least after the initial stages of the plating cycle.

Control grids have been employed in D.C. plasma discharge sputter plating apparatus such as that described in U.S. Pat. 3,361,659. However, the character of that type of discharge is quite different from that obtained in a radio frequency discharge as emloyed in the present invention. The mode of operation of the grids in a D.C. discharge system is nonanalogous to the mode of operation of such grids in an R.F. discharge system.

SUMMARY OF THE INVENTION

The principal object of the present invention is the provision, in an R. F. sputter plating method and apparatus, of control of ion and electron bombardment of the plating.

One feature of the present invention is the provision, in an R.F. sputter plating apparatus, of a structure disposed intermediate the plasma discharge region and the collector electrode structure such grid structure being operative with the collector potential for controlling bombardment of the collector structure by ions and electrons passing out of the plasma discharge region by application of suitable potentials to said grid structure and collector structure, whereby the deleterious effects of ion and electron bombardment of the deposited materials are avoided in use.

Another feature of the present invention is the same as the preceding feature wherein a first grid is disposed adjacent the plasma discharge and is operated at essentially ground potential to define one side of the plasma discharge without substantially perturbing the discharge.

Another feature of the present inevntion is the same as any one or more of the preceeding features wherein a second grid is disposed intermediate a first grid structure and the collector structure, such second grid being operated at a positive potential relative to the potential of the plasma to reflect positive ions emanating from the plasma discharge, whereby ion bombardment of the plating is controlled.

Another feature of the present invention is the same as any one or more of the preceding features wherein the collector electrode structure is operated at a negative potential relative to ground and preferably also negative with respect to the self-bias potential on the R.F. electrodes for reflecting electrons that have passed from the discharge through the first and second grids, whereby electron bombardment of the sputtered material deposited on the collector structure is controlled.

Another feature of the present invention is a method for R.F. sputter plating wherein the ion and electron bombardment of the collected sputtered material is controlled by producing suitable barrier potentials in the path of the sputtered target material between the radio frequency plasma discharge zone and the collecting structure for re-

pelling both positive ions and the electrons emanating from the discharge.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic line diagram of a radio frequency sputter apparatus of the present invention,

FIG. 2 is an enlarged cross-sectional view of a portion of the structure of FIG. 1 delineated by lines **2**—**2**, and

FIG. 3 is a plot of potential versus distance taken along line **3**—**3** of FIG. 2 depicting the potential barriers for reflecting ions and electrons back to the plasma zone.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown in schematic line diagram form, a radio frequency sputter plating apparatus **1** incorporating features of the present invention. This apparatus is of the general type descripe in the aforementioned article and has an inverted V-shaped configuration for the sputter electrodes. However, the electrodes need not be of the inverted V configuration but may, alternatively, be parallel to each other and disposed parallel over the substarte member. Since these R.F. sputter plating apparatuses are commercially available and are described in the published literature they will not be described in detail in the present disclosure. Only the additional features of the control devices for controlling ion and electron bombardment of the plated surfaces will be described in detail.

Briefly, the R.F. sputter plating apparatus **1** includes a bell jar **2** forming an evacuable chamber in gas commnication with a vacuum system **3** utilized for evacuating the bell jar to a suitable operating pressure, such as 2×10^{-3} torr. A suitable ionizable gas, such as argon, is utilized as the fill for the bell jar such that an intense plasma discharge may be obtained. A pair of R.F. electrodes **4** are supported within the bell jar **2** and are preferably arranged in an inverted V-shaped configuration. Suitable R.F. electrodes **4** are made of, for example, copper. The electrodes **4** are connected across the secondary of a radio frequency transformer **5**, the primary of which is excited from a radio frequency generator **6** at a suitable radio frequency, such as 13.5 mHz. The transformer **5** is an isolation transformer permitting a D.C. potential to be established on the secondary to be independent of the D.C. potential on the primary circuit. In other words, the secondary circuit, including the R.F. electrodes **4**, is at a floating D.C. potential. Although the electrodes **4** are shown in the inverted V-shaped configuration, other suitable configurations would include the planar configuration where electrodes **4** are parallel to each other and parallel to the surface of a collector electrode structure **7** which is disposed facing the electrodes **4**.

The collector electrode structure **7** is preferably water cooled in the conventional manner and is adapted to support, on its surface facing the electrodes **4**, the items or devices **8** which it is desired to plate. A target material **9** which it is desired to sputter, such as copper, gold, alumina, or the like, is carried from the inner faces of the R.F. electrodes **4**. A variable capacitor **11** is connected across the secondary winding of the transformer **5** for impedance matching the impedance of the source **6** to the impedance of the plasma discharge established in the region between the R.F. electrodes **4**. A typical value for the capacitance of capacitor **11** is from 17 to 72 picofarads. A pair of grid electrode structures **12** and **13** are disposed over the face of the collector electrode **7** and are supported therefrom in the manner as depicted in FIG. 2.

Referring now to FIGS. 1 and 2, it is seen that grids **12** and **13**, as of 100 mesh grid, i.e., 100 meshes to the inch and made of 1 mil diameter wire, are supported in suitable frame structures from the collector structure **7** via the intermediary of sputter shielded insulator assemblies **15** and **14**, respectively. The first or inside grid **12** is preferably operated at approximately ground potential, whereas the second grid **13** is preferably operated at a relatively low positive potential, as of +200 volts, as derived from a power supply **16** via potentiometer pick-off **17**. The collector electrode **7** is preferably operated at a very substantial neagtive potential as of —2500 volts, as derived from power supply **16** via potentiometer pick-off **18**. Grids **12** and **13** preferably have as high a transparency for sputtered material as possible and the aforementioned grids having 100 mesh and 1 mil wire provide approximately 80% transmission such that material sputtered from targets **9** passes through the grids **12** and **13** and is deposited upon the devices **8** to be plated.

In opeartion, the radio frequency energy applied across the R.F. electrodes **4** produces a radio frequency plasma discharge in the region between the plates **4** resulting in a plasma discharge zone **19**. In the plasma discharge zone **19** there are approximately as many positive ions as negative electrons such that the plasma zone is electrically neutral and at a relatively low potential with respect to ground, such as +100 volts, depending upon the gas utilized in the discharge and the pressure of the discharge.

The plasma discharge zone **19** extends almost to the surfaces of the target electrode portions **9** and to the grounded grid **12**. More specifically, it is found that a dark space sheath of approximately 1.8 centimeters in thickness is found immediately adjacent the interior surfaces of the target electrode portions **9**, whereas the dark zone between the grid **12** and the plasma discharge zone **19** is approximately 2 millimeters wide.

In the presence of the R.F. plasma discharge, the electrodes **4** and **9** assume a negative D.C. potential which is approximately equal to the magnitude of the average of the peak-to-peak amplitude of the applied R.F. potential impressed across the plates **4** and **9**. This relatively large D.C. self-bias potential which develops on electrodes **4** and **9** has been attributed to the high mobility of the electrons relative to that of the ions. Thus, during one cycle of operation, more electrons are attracted to any one of the plates **4** or **9** during the positive half cycle than there are ions attracted during the negative half cycle, such that a negative charge builds up on each of the electrodes **4** including the target electrodes **9**, if they are conductive and are conductively connected to the electrodes **4**. The end result is that both electrodes **4** and the target electrodes **9**, when they are conductive, acquire a large negative D.C. potential with respect to the plasma, such potential typically falling within the range of —1 kv. to —3 kv. and being a function of the gas utilized to form the plasma discharge and the pressure of the discharge.

In operation, positive ions within the discharge zone **19** are accelerated across the dark sheath and bombard the target electrode **9** with an energy corresponding to the D.C. bias, namely, typically about 2.3 kv. This results in sputtering of the target material. The sputtered material passes through the discharge zone **19** and impinges upon the devices **8** to be plated, as carried upon the collector structure **7**. The grid structures **12** and **13** are made sufficiently transparent such as not to intercept a substantial portion of the sputtered material. Typical transparencies for the grids **12** and **13** are approximately 80%.

When the positive ions bombard the target material **9**, in addition to dislodging target material, these particles also knock out secondary electrons in accordance with the secondary emission ratio of the target material. These secondary electrons "see" the R.F. voltage as superimposed upon the self-bias voltage and under certain phase angles of the R.F. voltage see very substantial accelerating voltages which propel the second electrons in a direction normally to the electrodes **4** and **9** back into and through the plasma discharge zone **19**. Since the discharge zone is operating at relatively low pressure, for example, 1×10^{-3}

torr to 3×10^{-3} torr, the mean free path for the electrons is on the same order of magnitude as the typical dimensions of the evacuated system and, therefore, a large fraction of the propelled secondary electrons will pass through the discharge zone **19** and, in the absence of a barrier potential on grids **12** and **13**, through the grids **12** and **13** to strike the plating which is being deposited upon the devices **8** on the collector electrode **7**. However, in use, as shown in FIG. 3, the potential applied to the collector structure **7** and devices **8** is of a sufficiently negative potential to repel or reflect the high energy electrons which have passed through grids **12** and **13**. By varying the potential picked off by pick-off **18** on the power supply **16** the amount of electron bombardment of the devices **8** may be controlled.

In addition, positive ions are present in the plasma discharge zone **19**. Since the plasma zone discharge zone **19** is operating at a potential slightly positive with respect to ground a certain small fraction of the positive ions within the discharge will be drawn out of the discharge and propelled through the grounded grid **12** toward the collector structure **7**. By applying a positive potential to the second grid **13** relative to the plasma potential, typically +150 volts, such ions can be reflected by the grid **13** and returned to the plasma zone **19**. In operation, a potential of approximately +200 volts on grid **13** is found sufficient to reflect the positive ions back to the plasma discharge zone **19**, when the zone **19** is operating at a potential of approximately +150 volts with respect to ground potential. A grounded shield **21** surrounds the electrodes **4**, **12**, **13**, and **7** for confining the plasma discharge to the desired zone **19**.

Thus, both positive ion and electron bombardment of the plated devices **8** can be controlled during the plating process by selection of the correct potentials applied to grids **12**, **13** and collector **7**. It is found that some bombardment of the surface being plated is desired during the initial phases of the plating process. It is believed that this bombardment of the surface serves to increase the adhesion between the plating and the surface being plated by removing surface contaminants or by the formation of surface defects serving as nucleation sites for the plating. However, in some cases, during the major portion of the plating time and particularly during the final portion of the plating cycle, it is desired not to have substantial bombardment of the plating by either the electrons or the ions as this bombardment can cause substantial overheating of the film being plated and can also result in destruction of the substrate or surface on which the plating is being deposited. The result is that poor adhesion is obtained and even flaking is obtained in some cases. In the case of copper plating, an additional effect is to reduce the reflectivity of the surface.

In some cases, it is conceivable that it may be desirable to bombard the surface being plated with the ions and not the electrons. In such a case, the potential applied to the ion reflecting grid **13** is selected via pick-off **17** such that the ions are not repelled by the second grid **13**. Once the ions pass through the grid **13** they are accelerated and propelled against the surfaces being plated as carried on the collector electrode **7**. However, the high negative potential applied to the collector structure **7** can prevent the electrons from reaching the plating.

Thus, by adjusting the potential of grids **12**, **13** and the collector structure **7**, the ion and electron bombardment of the surfaces being plated can be readily controlled

while the plasma zone remains substantially undisturbed due to the presence of the grounded grid structure **12**.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A radio frequency sputtering apparatus comprising means defining a pair of radio frequency electrode structures, means for impressing a radio frequency potential across said pair of radio frequency electrodes to produce a radio frequency plasma discharge, means forming a target electrode structure including material to be sputtered and disposed such as to be bombarded by ions emanating within said plasma discharge region, means forming a collector electrode structure disposed to receive target material sputtered from said target electrode structure, means forming a grid electrode structure having first and second portions disposed intermediate said plasma discharge region and said collector electrode structure and operative with said collector structure by application of suitable electrical potentials thereto for controlling bombardment of said collector electrode structure by charged particles passing out of said plasma discharge region, means for applying substantially ground potential to said first portion of said grid structure, said first portion of said grid structure being disposed adjacent said plasma discharge region whereby said first portion of said grid structure defines one side of said plasma discharge region without substantially perturbing the discharge, said second portion of said grid structure being insulated from said first portion and disposed intermediate said first grid portion and said collector structure, and means for applying a positive potential to said second grid portion relative to said first portion to control passage of positive ions emanating from said plasma discharge.

2. The apparatus of claim **1** including, means for applying a negative potential to said collector structure relative to ground potential for controlling passage of electrons from said plasma discharge region to said collector electrode whereby electron bombardment of the sputtered material deposited on said collector structure is controlled.

3. The apparatus of claim **2** wherein said means for applying a negative potential applies a potential which is negative with respect to a self-bias D.C. potential established on said pair of radio frequency electrodes.

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