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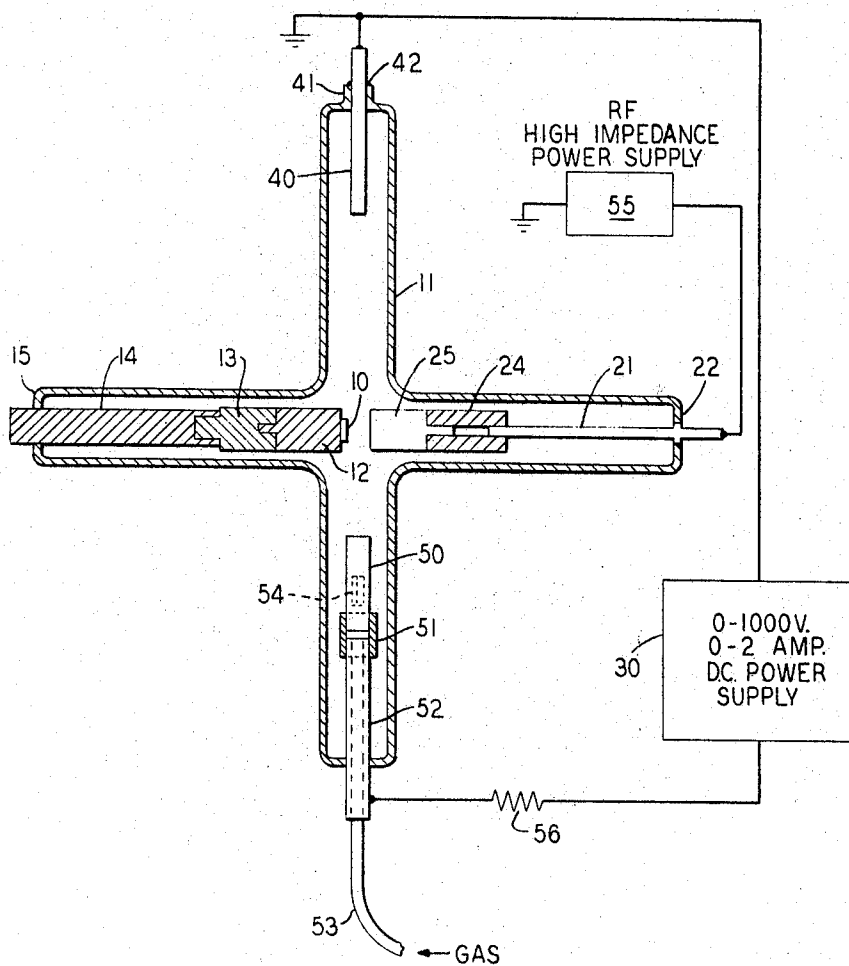
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APPARATUS FOR PLASMA PROCESSING

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2 Sheets-Sheet 1

FIG. 1



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FIG. 2

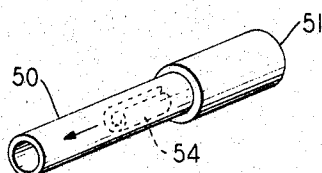


FIG. 3A

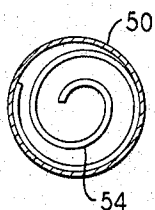


FIG. 3B

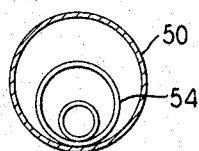


FIG. 4A

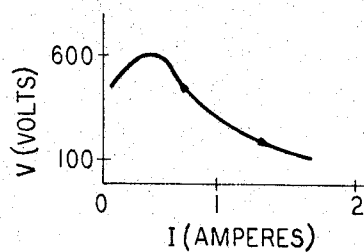
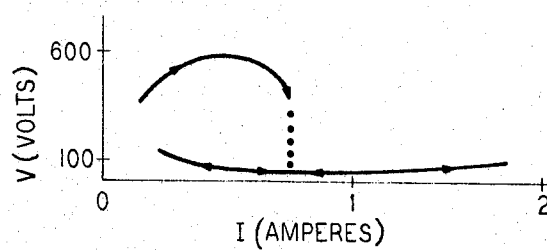


FIG. 4B



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APPARATUS FOR PLASMA PROCESSING

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4 Claims

ABSTRACT OF THE DISCLOSURE

The specification describes a hollow tantalum cathode designed especially for creating high discharge plasmas in connection with processes for depositing thin films. The hollow cathode contains an auxiliary element which decreases the operating power and enhances the reproducibility of the discharge.

This invention relates to apparatus for plasma deposition processes.

In recent years there have been several proposals for depositing insulating films on various substrates using the reactive environment of an ion plasma to create the insulating compound. U.S. Patent No. 3,287,243 issued Nov. 22, 1966, is exemplary of these processes. This patent describes a process in which a semiconductor cathode is sputtered in such a way that the sputtered material traverses a reactive ion plasma and deposits on an anodic substrate as the desired insulating compound. The plasma contains the anion specie. This process is of particular interest for producing films of silicon oxide or silicon nitride in the processing of passivation of silicon semiconductor devices. The plasma in this case is maintained by a microwave generator situated externally of the reaction chamber.

A related process is described in Patent No. 3,424,661, issued Jan. 28, 1969 to A. Androschuk, A. A. Bergh and W. C. Erdman, which has the similar objective of depositing insulating films of compounds such as silicon oxide or silicon nitride. This process uses a reactive gas plasma which may be supported by a hot cathode filament. The cation can be derived from a gaseous compound such as a silicon tetrahalide. There is no cathodic sputtering associated with this process. One of the features of this process is the isolation of the filament cathode from the reactive gas by a system of differentially pumped gases. The cathode is maintained in an atmosphere of nitrogen or inert gas at all times.

A common requirement of these and other processes is the use of a relatively dense reactive gas plasma. This invention is directed to a novel apparatus for forming and maintaining the reactive gas plasma. It involves the use of a hollow tantalum cathode of a specific design as the means for creating the electric discharge. This cathode functions in nitrogen or inert gases and is capable of discharge currents up to several hundred amperes. Plasmas created by such large currents can be quite dense, of the order of 10^{13} to 10^{15} electrons/cm.³. In sputtering, the high electron density increases the sputtering rate. In gas reactions, as described in the application noted above, the high electron density effectively promotes the rate of reaction. In both cases high growth rates result. The high electron capacity of the cathode of this invention can create a plasma having a rather large volume. This latter consideration can be important in a commercial apparatus where a maximum number of substrates is desirably exposed to the plasma at one time. The cathode itself has distinct advantages over hot filaments in terms of useful life. Also it does not require an auxiliary power supply as does the hot filament. The novel cathode comprises a

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hollow tantalum tube containing an auxiliary electron emitter within the hollow portion of the tube.

These and other aspects of the invention will become more apparent from the following more detailed description. In the drawing:

FIG. 1 is a schematic diagram, partly in section, of an apparatus utilizing the hollow tantalum cathode;

FIG. 2 is a perspective view of the hollow tantalum cathode;

FIG. 3A is a front elevation of a hollow cathode showing one embodiment of the auxiliary electron emitter;

FIG. 3B is a front elevation showing another embodiment of the auxiliary electron emitter;

FIG. 4A is a current-voltage plot illustrating qualitatively the typical behavior of a hollow tantalum cathode element without the auxiliary electron emitter; and

FIG. 4B is a current voltage plot similar to that of FIG. 4A illustrating the emission characteristics of the same hollow cathode with the auxiliary electron emitter.

FIG. 1 shows an apparatus for depositing thin films of tantalum nitride. The substrate 10 is mounted on a pedestal within a sealed quartz envelope 11. The pedestal 12 is an aluminum block seated into a copper block 13. A copper sleeve 14 is brazed to support block 13. The sleeve 14 is sealed within a removable section 15 of the quartz envelope. The sputtering electrode comprises a silicon support rod 21 sealed in the terminal tube section 22. The rod 21 supports an aluminum sleeve 24. The cathode 25 is held in the inner end of the sleeve 24. The sputtering electrode in this apparatus is pure silicon. The sputtering electrode 25 is connected to a high impedance RF power supply which normally delivered 400 watts at 27.1 MHz. The sputtering field showed greater stability in operation with the anode grounded.

Electrode 40, is a water-cooled (cooling means not shown) one-half inch diameter anode sealed in the upper arm of the quartz envelope 11 with a Kovar to glass seal 41 and solder joint 42. The anode is used to create the plasma in association with the hollow tantalum cathode 50. The anode 40 in this apparatus was gold-plated copper although the size and composition of the anode is not critical. The hollow cathode is supported by a hollow tantalum sleeve 51. The sleeve is attached to a hollow Kovar tube 52 which is sealed in the lower arm of the envelope. A gas tube 53 is attached to the support sleeve for admitting gas, in this case nitrogen, to the reaction zone of the quartz envelope. The auxiliary electron emitter 54 is shown in phantom in the hollow tantalum cathode. It consists of a rolled tantalum foil and will be described in more detail below. The hollow cathode and anode 40 are connected through a ballast resistor 56 (375 ohms) to the D.C. power source 30.

FIG. 2 illustrates the hollow cathode 50 and the associated hollow tantalum sleeve 51 more clearly. The hollow tantalum tube is two inches long. The overall length is not critical although it should exceed one inch since the normal hot zone is about one inch long during high power operation. The tube has a preferred outside diameter in the range of one-eighth inch to one-half inch and a wall thickness of one mil to ten mils. These dimensions have been found to be quite important to obtaining proper electron emission and useful cathode life. For instance, the cathode itself sputters internally during normal operation and, although most of the material sputtered off the inside of the tube redeposits, there is a redistribution of this material. Therefore if the wall thickness is much less than one mil, holes can develop. If the wall is very thick it requires excessive power to heat the localized emitting region to the temperature required to produce free electrons. It has also been found that if the tube diameter (O.D.) is not maintained in the prescribed range that the emission behavior becomes

unstable. The hot zone where the electrons are emitted should be positioned in a region spaced from the end of the tube. If the hot region includes the end of the tube sputtering will erode the tip of the tube and a relatively uncontrolled emission occurs. If the tube has the prescribed dimensions, a stable hot zone can be maintained. The optimum dimensions are in the middle of the ranges (one-quarter inch O.D., 5 mils thick).

The auxiliary electron emitter 54 is a rolled, five mil, tantalum foil, one inch wide and two inches long. It can be positioned in the tube at any distance between the tube face to several inches back without affecting the performance of the cathode. The active hot region will always form from the face of the auxiliary electron emitter. The configuration of the auxiliary emitter can vary. Two embodiments are illustrated in FIGS. 3A and 3B. These figures show end views of the tube 50 and the configuration of the auxiliary emitter 54. The auxiliary elements of FIG. 3B can also be concentrically mounted.

Various experiments with several forms of auxiliary emitters have established that the necessary structural requirement is an elongated edge either continuous as in FIG. 3A or semi-continuous as in FIG. 3B. The shape itself is unimportant. The edge can be star-shaped or corrugated. The simplest structures are those shown in FIGS. 3A and 3B. The length of the edge or edges should be at least equivalent to the circumference of the tube, i.e., three-eighths inch for one-eighth inch O.D. and one and one-half inches for one-half inch O.D. The edge, under normal circumstances, will be within three inches of the end of the tube. The length of the auxiliary emitter in the axial direction of the tube is not critical and any convenient length will do. In most of the experiments done in connection with the invention the length of the foil was in the range of one-quarter inch to two inches. The thickness of the foil forming the secondary emitter should follow the same prescription given for the tube.

The following example is given as exemplary of one process (described with reference to the apparatus of FIG. 1) in which the hollow cathode of the invention can be used.

Nitrogen gas is admitted through inlet 52 to maintain a nitrogen pressure in the reaction chamber of 0.1 mm. to 10 mm. The substrate 10 is silicon. The object of this process is to deposit silicon nitride on the substrate. The substrate can be almost any solid, stable material, e.g., germanium, gallium arsenide, glass or ceramic. The RF sputtering electrode 25 provides the cation for the compound being deposited, in this case, silicon. Alternatively the cation may be derived from a gaseous compound such as a silicon halide. In this latter event the gas would be admitted at a location removed from the hollow cathode since the hollow cathode would rapidly deteriorate in the corrosive halide environment. An apparatus such as that described in application Ser. No. 614,095, filed Apr. 28, 1967 by A. Androshuk, A. A. Bergh and W. C. Erdman could be used to maintain the electrode isolated from the corrosive plasma. The hollow cathode functions well in nitrogen or any of the inert gases.

The apparatus of FIG. 1 can be operated with one-tenth ampere to several hundred amperes through the hollow cathode. Electron densities of 10^{13} to 10^{15} electrons/cm.³ are produced. The spacing between all electrodes is only important insofar as it affects the voltage drop. Spacings of several inches between electrodes 40 and 50 can be used with voltages of one hundred fifty volts. Electrodes 25 and 12 should be closely spaced to avoid unwanted deposits on adjacent areas.

The deposit, silicon nitride, forms at a rate of the order of 500 A. per minute. The substrate surface generally remains below 350° C. This relatively low operating temperature is a well-known virtue of plasma deposition processes.

The performance of the hollow cathode was evaluated with and without the auxiliary electron emitter and data obtained is qualitatively plotted in FIGS. 4A and 4B.

FIG. 4A shows the current-voltage characteristic obtained without the auxiliary emitter and FIG. 4B gives the corresponding data with the auxiliary emitter in place. The characteristic of FIG. 4A is not unusual and shows the normal power reduction as breakdown is exceeded. The characteristic of FIG. 4B however is quite unusual. A bistable characteristic is obtained with the auxiliary emitter. When the cathode is initially energized the high resistance curve is traced until breakdown. Then the cathode operates in the low resistance state and it remains in this state until the cathode is de-energized. The cathode will then return to the high resistance state when it is subsequently energized. The effect is undoubtedly a thermal effect which is, practically speaking, instantaneous. However, the consequences are a marked drop in operating power. Another advantage observed with the auxiliary emitter was a considerably more stable and reproducible emission behavior.

The hollow cathode of this invention is especially useful in processes for depositing nitrogen compounds by reactive sputtering or reactive plasma deposition. This is due to the ability of the cathode to function well in a nitrogen gas ambient. Although the tantalum becomes nitrided, tantalum nitride is sufficiently conductive to permit a continued flow of electrons from the hot region of the cathode. As previously indicated the cathode can be operated in an inert gas atmosphere. Although the invention has been described in connection with a specific type of coating process the cathode is useful for any process in which a high concentration of electrons is desired. Accordingly, the invention is directed principally to the cathode structure per se and, secondarily, to apparatus useful in preferred embodiments.

The process described in detail above can take place without admitting nitrogen to the system. In this case the material of the sputtering electrode 25 (silicon in the specific example) would be deposited rather than the nitride compound. The operating parameters would be essentially identical except that the ambient would normally be an inert gas such as argon or helium.

Various additional modifications and extensions of this invention will become apparent to those skilled in the art. All such variations and deviations which basically rely on the teachings through which this invention has advanced the art are properly considered within the spirit and scope of this invention.

What is claimed is:

1. A hollow cathode comprising a hollow tantalum tube having an outside diameter in the range of one-eighth inch to one-half inch and a wall thickness in the range of one mil to ten mils, and an auxiliary electron emitter positioned within the tube, the emitter being composed of tantalum foil having a thickness in the range of one mil to ten mils, the foil being placed in the tube with a substantial portion of its edge lying approximately in a plane normal to the axis of the tube, the edge having a length at least equal to the circumference of the tube.

2. An apparatus for depositing thin films comprising a reaction chamber, a cathode mounted within the chamber in spaced relationship to a substrate upon which the film is to be grown, means for establishing a plasma in the region between the cathode and the substrate said means comprising an anode and a hollow tantalum cathode, the tantalum cathode comprising a hollow tantalum tube having an outside diameter in the range of one-eighth inch to one-half inch and a wall thickness in the range of one mil to 10 mils, and an auxiliary electron emitter positioned within the tube, the emitter being composed of tantalum foil having a thickness in the range of one mil to ten mils, the foil being placed in the tube with a substantial portion of its edge lying approximately in a plane normal to the axis of the tube, the edge having a length at least equal to the circumference of the tube.

3. The apparatus of claim 2 additionally including means for introducing a gas into the reaction chamber.

4. An apparatus for depositing thin films comprising a reaction chamber, means for evacuating the chamber, a substrate mounted within the chamber upon which the thin film is to be deposited, means for admitting reactive gases into the chamber and at least two electrodes for establishing a plasma in the region of the substrate one of said electrodes comprising a hollow tantalum tube having an outside diameter in the range of one-eighth inch to one-half inch and a wall thickness in the range of one mil to ten mils, and an auxiliary electron emitter positioned within the tube, the emitter being composed of tantalum foil having a thickness in the range of one mil to ten mils, the foil being placed in the tube with a substantial portion of its edge lying approximately in a plane normal to the axis of the tube, the edge having a length at least equal to the circumference of the tube.

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U.S. Cl. X.R.

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