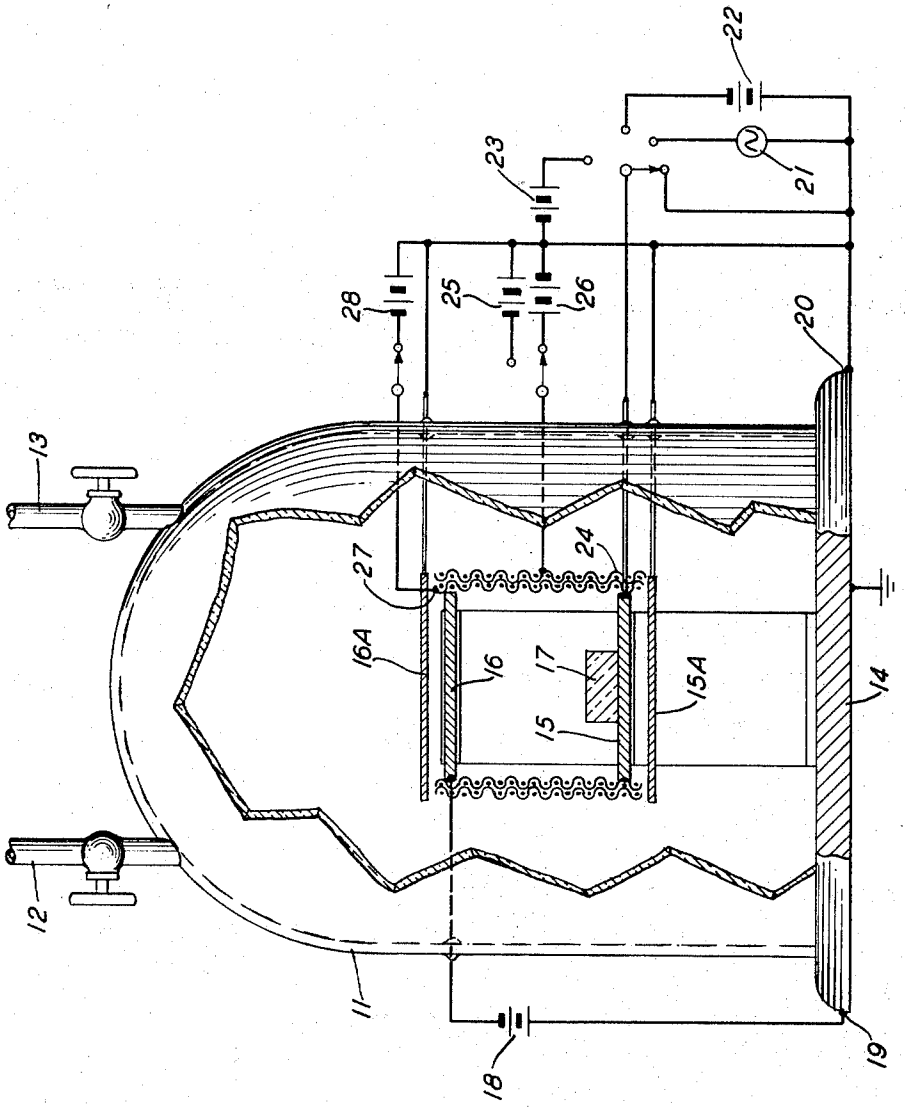
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ELECTROSTATIC CONTROL OF ELECTRON MOVEMENT IN CATHODE SPUTTERING

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ELECTROSTATIC CONTROL OF ELECTRON MOVEMENT IN CATHODE SPUTTERING

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The present invention relates to a technique for the deposition of thin films by cathodic sputtering.

In recent years, considerable interest has been generated in the electronics industry in thin film components and circuits prepared by cathodic sputtering techniques. Although widely practiced, certain limitations have precluded total exploitation of the sputtering procedure. Thus, limited deposition rates during conventional sputtering have often adversely affected electrical and structural parameters as well as economies.

In accordance with the present invention, a technique for enhancing the deposition rate during cathodic sputtering is described wherein the aforementioned drawbacks are appreciably lessened. The inventive technique involves sputtering in a system employing electrostatic reflection of electrons by means of a negative bias on a sputtering screen or pseudo-anode in order to prevent loss of energetic electrons from the ionization region or, in the alternative, by means of a selective positive potential on a dual screen which prevents the loss of electrons by effectively removing the fraction of electrons that are likely to undergo recombination and reflecting ions back into the sputtering plasma. The system utilized includes three electrodes, an anode, a cathode and a third electrode, and in which the anode member is biased positive or negative with respect to the third electrode or in the alternative maintained at ground potential, the cathode member being biased at conventional potentials with respect to the anode. The system also includes a sputtering screen or plate structure which may be biased positive or negative with respect to the anode depending upon the type of control sought. In other words, variation in screen potential permits control over the type of structure produced as well as the electrical properties thereof.

The invention will be more readily understood by reference to the following detailed description, taken in conjunction with the accompanying drawing wherein:

The figure is a schematic view of an exemplary apparatus suitable for the practice of the present invention.

With reference now more particularly to the figure, there is shown a vacuum chamber **11** provided with an outlet **12** for connection to a vacuum pump (not shown), an inlet **13** for the introduction of an inert or reactive gas or mixtures thereof during the sputtering process, and a base plate **14** which serves the purpose of a third or ground electrode. Shown disposed within chamber **11** is a substrate holder or anode member **15** and a cathode member **16**, the latter being comprised of the material which is required to be deposited upon substrate member **17**. Sputtering shields **15A** and **16A** reduce sputtering from the backside of the cathode and sample holder during the operation of the process. Cathode member **16** is connected to the negative pole **18** of a direct current high potential supply, the positive pole of which is connected to base plate **14**, as at **19**. Anode member **15** may be connected to (a) base plate **14**, as at **20**, (b) a source of alternating current **21**, one side of which is connected to base plate **14** (as at **20**), (c) the negative pole **22** of a direct current source, the positive pole of which is connected to base plate **14** (as at **20**) or (d) the positive pole **23** of a direct current source, the negative pole of which is connected to base plate **14** (as at **20**). Also shown disposed within chamber **11** is a sputtering screen

24 which may be connected to (a) the negative pole **25** of a direct-current source, the positive pole of which is connected to base plate **14** (as at **20**), or (b) the positive pole **26** of a direct-current source, the negative pole of which is connected to base plate **14** (as at **20**). In those situations when it is desirable to apply a positive bias to screen **24**, it has been found necessary to employ a second sputtering screen **27** in order to avoid a loss of electrons in the sputtering plasma. Under these circumstances screen **27** is connected to the negative pole **28** of a direct-current source, the positive pole of which is connected to base plate **14**, as at **20**.

The present invention may conveniently be described by reference to an illustrative example wherein it is desired to cathodically sputter manganese or any of the well known film-forming metals, for example, tantalum, niobium, titanium, zirconium, aluminum, et cetera, in an apparatus of the type shown in the figure.

Substrate **17** is first vigorously cleaned. Conventional cleaning agents are suitable for this purpose, the choice of a particular one being dependent upon the composition of the substrate itself. Substrate **17** is then placed upon substrate holder **15**, as shown in the figure, the latter being composed of a suitable conductor, typically, the material it is desired to deposit or any material compatible therewith. The vacuum techniques utilized in the practice of the present invention as known (See, "Vacuum Deposition of Thin Films," L. Holland, J. Wiley & Sons, Inc., New York, 1956.) In accordance with such procedures, the vacuum chamber is first evacuated, flushed with an inert gas, as for example, any of the members of the rare gas family such as helium, argon or neon and the chamber re-evacuated. The extent of the vacuum required is dependent upon consideration of several factors which are well known to those skilled in the art. However, for the purposes of the present invention, a practical initial pressure range is 10^{-5} to 10^{-7} torr while suitable inert gas pressure during sputtering ranges from 10^{-3} to 10^{-1} torr.

After the requisite pressure is attained, cathode **16** which may be composed of any of the above-noted film-forming metals or, alternatively, may be covered with any of the film-forming metals, for example, in the form of a foil, is made electrically negative with respect to base plate **14**.

The minimum voltage necessary to produce sputtering is dependent upon the particular film-forming metal employed. For example, a direct-current potential of approximately 1000 volts may be employed to produce a sputtered layer of tantalum suitable for the purposes of this invention, minimum voltages for other film-forming metals being well known to those skilled in the art. However, in certain instances it may be desirable to sputter at voltages greater than or less than the noted voltage.

The next step in the inventive procedure involves connecting substrate holder **15** and substrate **17** in such manner that they are maintained at ground potential or made electrically positive or negative with respect to base plate **14**, as described above. This end may be attained by (a) maintaining a ground potential, (b) applying a positive or negative direct-current potential or (c) an alternating current potential.

For the purposes of the present invention, it has been found that if holder **15** is to be maintained at a potential, with respect to base plate **14**, other than ground it may be at least ± 1 volt D-C and range up to $+1000$ volts on the positive side plus over minus and and approximately -5000 volts on the negative side. Alternatively, an A-C potential ranging up to 5000 volts may be applied to the ungrounded substrate holder, so attaining similar results.

Next, a D-C potential of at least ± 1 volt is applied

to screen **24** in order to control the electron density in the sputtering plasma. This potential may range up to +1000 volts on the positive side and approximately −2000 volts on the negative side, in both cases the pinch off voltage (that voltage at which the sputtering rate drops to zero) dictating the maximum. As noted previously, when a positive bias is applied to screen **24**, it is necessary to apply a negative bias to screen **27** ranging up to 1000 volts in order to reflect electrons back into the plasma. This voltage is essentially comparable to or in excess of the ionization voltage of the sputtering ion.

The spacing between the substrate holder and cathode is not critical. However, the minimum separation is that required to produce a glow discharge. For the best efficiency during the sputtering process, the substrate should be positioned immediately without the well known Crooke's Dark Space.

The balancing of the various factors of voltage, pressure and relative positions of the cathode and substrate holder to obtain a high quality deposit is well known in the sputtering art.

With reference now more particularly to the example under discussion, by employing a proper voltage pressure and spacing of the various elements within the vacuum chamber, a layer of film-forming metal is deposited upon substrate **17**. Sputtering is conducted for a period of time calculated to produce the desired thickness.

Several examples of the present invention are described in detail below. These examples are included merely to aid in the understanding of the invention, and variations may be made by one skilled in the art without departing from the spirit and scope of the invention.

Example I

This example describes the preparation of a sputtered tantalum film.

A cathodic sputtering apparatus similar to that shown in the figure was used to produce the tantalum layer. In the apparatus employed, base plate **14** and anode **15** were grounded, the cathode being biased at 4000 volts negative with respect to ground. Screen **24** was biased at 1000 volts negative with respect to ground.

A glass microscope slide was used as the substrate. The substrate was washed in a non-ionic detergent followed by a sequential rinse in water, hydrogen peroxide and distilled-deionized water. The tantalum cathode was employed in the form of an arc melted ingot slab.

The vacuum chamber was initially evacuated to a pressure of the order of 10^{-6} torr, flushed with argon and re-evacuated to a partial argon pressure of 20 millitorr.

The substrate holder and cathode was spaced 3 inches apart, the substrate being placed upon the former. A direct-current voltage of −4000 volts was impressed between cathode and base plate **14** and −1000 volts between screen **24** and base plate **14**.

Sputtering was conducted for 45 minutes, so resulting in a tantalum film 4410 angstroms thick, the deposition rate being approximately 98.4 angstroms/minute. The resultant film evidenced a specific resistivity of 103 micro-ohm centimeters.

For comparative purposes, the procedure described above was repeated with and without a negative bias on screen **24**. The results are set forth in the table below.

TABLE I

Example	Screen Potential (Volts)	D.C. at Cathode (Volts)	Deposition Rate (A./min.)	Specific Resistivity (μ ohm-cm.)
1	−1,000	−4,000	107	67
2	−1,500	−4,000	120	37
3	−2,000	−4,000	128	40
4	−500	−4,000	98.4	103
5	−100	−4,000	84.0	118
6	(1)	−4,000	70.6	270
7	+120	−4,000	56.4	387

[1] Floating.

From the data, it was established that employing a cathode voltage of a negative four kilovolts, a grounded substrate and a positive potential on the screen, the deposition rate is approximately 60 A./min. and the specific resistivity 400 microhm-cm. The use of low negative potentials (0–100 volts) on the screen results in a deposition rate of approximately 70 A./min. whereas the application of negative potentials ranging up to −2000 volts results in an increase in deposition rate to a maximum of 128 A./min. while concurrently reducing specific resistivity to a minimum value of 37 microhm-cm. The films deposited over the range of positive to approximately 50 volts negative are of β-tantalum structure whereas films obtained at a screen bias in excess of −50 volts were 6 cc. tantalum.

Studies of the described technique have also revealed that the screen improves the uniformity of the deposited films. Thus, in an exemplary procedure, with a 4″ dia. cathode and a 3″ cathode to substrate spacing it was determined that the absence of the screen resulted in variations in sputtering rate of the order of ±23% for a specific geometric configuration. For comparative purposes, the procedure was repeated utilizing a screen of the type described herein, the variations in sputtering rate being of the order of ±8%.

What is claimed is:

1. A method for the deposition of thin films upon a substrate by cathodic sputtering in a vacuum chamber in which are disposed a first electrode, and a second electrode for supporting an electrical discharge and a sputtering screen coaxially surrounding said discharge which comprises the steps of evacuating the said vacuum chamber, admitting a sputtering gas into the said vacuum chamber, biasing the said second electrode negative with respect to said first electrode by means of a D-C potential to effect said electrical discharge and biasing the said screen at a fixed potential with respect to said first electrode.

2. A method in accordance with the procedure of claim **1** wherein said screen is biased negative with respect to said first electrode.

3. A method in accordance with the procedure of claim **1** wherein said screen is biased positive with respect to said first electrode.

4. A method in accordance with claim **1** wherein said thin film is tantalum.

5. A method in accordance with claim **1** wherein said thin film is manganese.

6. A method for the deposition of thin films upon a substrate by cathodic sputtering in a vacuum chamber in which are disposed a first electrode, and a second electrode for supporting an electrical discharge, a third electrode and a sputtering screen coaxially surrounding said discharge which comprises the steps of evacuating the said vacuum chamber admitting a sputtering gas into the said vacuum chamber, biasing the said second electrode at a fixed potential with respect to said first electrode to effect said electrical discharge and simultaneously biasing the said third electrode negative with respect to said first and second electrodes at a potential distinct from that of the said second electrode, and biasing the said screen at a fixed potential with respect to said first electrode.

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