April 20, 1971 D. GERSTENBERG ET AL 3,575,833

HAFNIUM NITRIDE FILM RESISTOR

Filed Feb. 26, 1968

FIG. 1

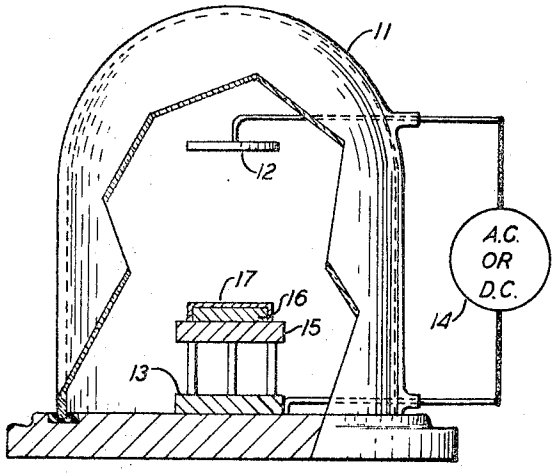


FIG. 3

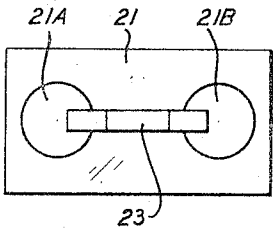
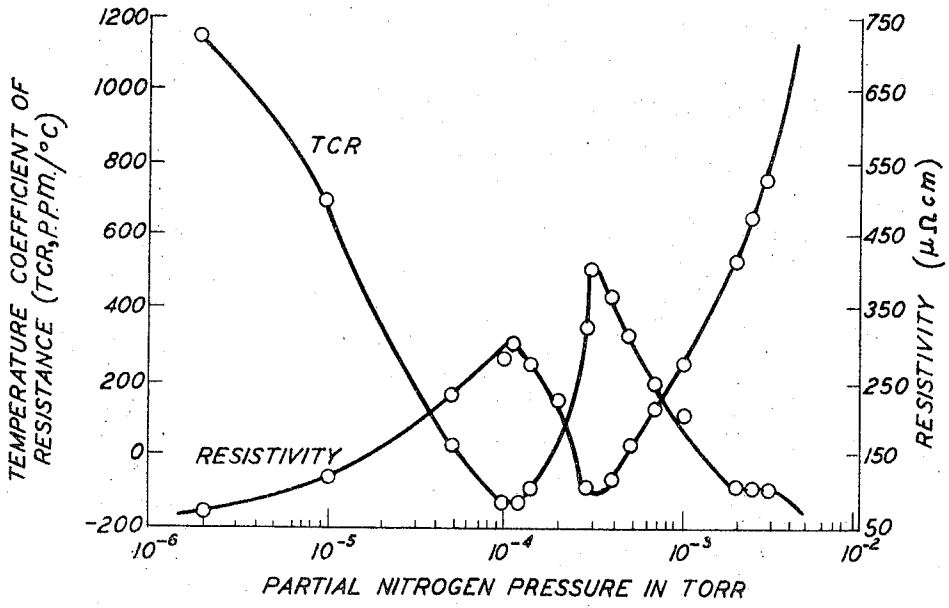


FIG. 2



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HAFNIUM NITRIDE FILM RESISTOR

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ABSTRACT OF THE DISCLOSURE

Hafnium nitride thin film resistors are obtained by sputtering hafnium in the presence of nitrogen maintained at partial pressures within the range of 10^{-4}–10^{-2} torr.

This invention relates to film resistors including a layer of hafnium nitride. More particularly, the present invention relates to film resistors of high stability including a reactively sputtered layer of hafnium nitride.

Recently, considerable interest in the microminiaturization field has been focused upon tantalum nitride film resistors of high stability which have been found to manifest electrical properties which compare favorably with those resistors commonly employed by the prior art workers. These structures are commonly prepared by reactively sputtering tantalum in the presence of nitrogen upon a suitable non-conducting substrate member. Although devices of this type have increased in popularity lately, inherent limitations on the range of available electrical properties have motivated a search for alternate structures.

In accordance with the present invention, the limitations alluded to hereinabove are effectively obviated by reactively sputtering hafnium upon a suitable substrate member in the presence of nitrogen at nitrogen partial pressures ranging from 10^{-4}–10^{-2} torr. Devices described herein have been found to evidence a wider range of homogeneity and, consequently, a wider range of electrical properties such as temperature coefficient of resistance and resistivity than the tantalum nitride structures. Specifically, it has been found that the resistors fabricated in accordance with the invention evidence resistivities ranging from 150–1000 microhm-centimeters over a range of temperature coefficients of resistance ranging from +500 to −500 parts per million per degree centigrade.

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

FIG. 1 is a front elevational view partly in section of an apparatus suitable for use in producing a film of hafnium nitride by reactive sputtering in accordance with the present invention;

FIG. 2 is a graphical representation on coordinates of resistivity in mircrohm-centimeters and temperature coefficient of resistance in parts per million per degree centigrade against the partial pressure of nitrogen in torr. showing the variations of resistivity and temperature coefficient of resistance in varying partial pressures of nitrogen at a total pressure of 20 millitorr. of argon; and

FIG. 3 is a plan view of a hafnium nitride film resistor prepared in accordance with the present invention.

With reference now more particularly to FIG. 1, there is shown an apparatus suitable for depositing a hafnium nitride film by cathodic sputtering. Shown in the figure

is a vacuum chamber **11** in which are disposed cathode **12** and anode **13**. Cathode **12** may be composed of hafnium or, alternatively, may serve as the base of the hafnium which later may be in the form of a coating, foil, or other suitable physical form.

A source of electrical potential **14** is shown connected between cathode **12** and anode **13**. Platform **15** is employed as a positioning support for substrate **16** upon which the sputtered film is to be deposited. Mask **17** is placed upon substrate **16** to restrict the deposition to this area.

The present invention is conveniently described in detail by reference to an illustrative example in which hafnium is employed as cathode **12** in the apparatus shown in FIG. 1. Preferred substrate materials for the practice of the present invention are glasses, glazed ceramics, and so forth. These materials meet the requirements of heat resistance and non-conductivity essential for substrates utilized in reactive sputtering techniques.

Substrate **16** is first vigorously cleaned. Conventional cleaning agents are suitable, the choice of a specific one being dependent upon the composition of the substrate itself. For example, when the substrate consists of glass, boiling in aqua regia or hydrogen peroxide is a convenient method for cleaning the surface.

Substrate **16** is placed upon platform **15**, as shown in FIG. 1 and mask **17** is then suitably positioned. Platform **15** and mask **17** may be fabricated from any refractory material. However, it may be convenient to use a metal such as aluminum for ease in the fabrication of mask **17**. In order to obtain sharply defined paths, it is necessary to have mask **17** bearing upon substrate **16** under externally applied pressure.

The vacuum chamber is next evacuated and nitrogen is admitted at a dynamic pressure, and after obtaining equilibrium, argon is admitted. The extent of the vacuum is dependent upon consideration of several factors.

Increasing the inert gas pressure and thereby reducing the vacuum within chamber **11** increases the rate at which the hafnium being sputtered is removed from the cathode and, accordingly, increases the rate of deposition. The maximum pressure is usually dictated by power supply limitations since increasing the pressure also increases the current flow between cathode **13** and anode **12**. A practical upper limit in this respect is 20 millitorr. for a sputtering voltage of 3000 volts, although it may be varied depending on the size of the cathode sputtering rate and so forth. The ultimate maximum pressure is that at which the sputtering can be reasonably controlled within the prescribed tolerances. It follows from the above discussion that the minimum pressure is determined by the lowest deposition rate which can be economically tolerated.

After the requisite pressure is obtained, cathode **12** which may be composed by hafnium or, alternatively, may be an aluminum disk covered with hafnium, for example, in the form of a foil, is made electrically negative with respect to anode **13**.

The minimum voltage necessary to produce sputtering is about 3000 volts. Increasing the potential difference between anode **13** and cathode **12** has the same effect as increasing the pressure, that of increasing both the rate of deposition and the current flow. Accordingly, the maximum voltage is dictated by consideraiton of the same factors controlling the maximum pressure.

The spacing between anode and cathode is not critical. However, the minimum separation is that required to produce a glow discharge which must be present for

sputtering to occur. Many dark striations are well known and have been given names, as, for example, Crooke's Dark Space (see Joos Theoretical Physics—Hafner, New York, 1950, page 435 etc.). For the best efficiency during the sputtering step, substrate **16** should be positioned immediately without the Crooke's Dark Space on the side closest to the anode **13**. Location of substrate **16** closer to cathode **12** results in a metal deposit of poorer quality. Locating substrate **16** further from cathode **12** results in the impingement on the substrate by a smaller fraction of the total metal sputtered, thereby increasing the time necessary to produce a deposit of given thickness.

It should be noted that the location of Crooke's Dark Space changes with variations in the pressure, it moving closer to the cathode with increasing pressure. As the substrate is moved closer to the cathode it tends to act as an obstacle in the path of gas ions which are bombarding the cathode. Accordingly, the pressure should be maintained sufficiently low so that Crook's Dark Space is located upon the point at which a substrate would cause shielding of the cathode.

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

With reference now more particularly to the example under disucssion, by employing a proper voltage, pressure, and spacing of the various elements within the vacuum chamber, a layer of hafnium nitride is deposited in a configuration determined by mask **17**. The sputtering is conducted for a period of time calculated to produce the desired thickness.

For the purposes of this invention, the mninmum thickness of the layer deposited upon the substrate is approximately 400 A. There is no maximum limit on this thickness although little advantage is gained by an increase upon 1500 A.

FIG. 2 is a graphical representation showing the resistivity in microhm-centimeters and temperature coefficient of resistance in parts per million per degree centigrade against the partial pressure of nitrogen in torr. The points on the graph represent the average over the inner six resistor strips on nichrome-gold terminated 1" x 3" glass slides which have been sputtered at a temperature of 350° C. at 4.0 kilovolts at a current density of 0.43 milliampere per square centimeter.

It is noted from the graph that at partial nitrogen pressures appreciably below 10^{-5} torr. there is little change in resistivity accompanied by a large increase in the temperature coefficient of resistance from +700 parts per million per degree centigrade to +1200 parts per million per degree centigrade. Above a partial pressure of nitrogen of 10^{-5} torr., the resistivity increases from 100 microhm-centimeters to a peak of 300 microhm-centimeters, corresponding with a partial pressure of 10^{-4} torr. Thereafter, resistivity decreases to a low point of approximately 100 microhm-centimeters and rapidly increases to values greater than 1200 microhm-centimeters at partial pressures of the order of 10^{-2} torr. It has been found that the temperature coefficient of resistance fluctuates from approximately +500 parts per million per degree centigrade to —500 parts per million per degree centigrade over a partial nitrogen pressure range of 10^{-4}–10^{-2}. In analyzing the data shown graphically in the figure, it must be noted that the indicated pressures are specific to the pumping speed of the particular vacuum system employed. Thus, it may be stated that the present invention is operable over a partial pressure of nitrogen range of 10^{-4}–10^{-2} torr.

In FIG. 3 there is shown a substrate member **21** composed of one of the refractory insulating materials usually employed in the construction of printed circuit boards which has deposited thereon two terminals, **21***a* and **21***b*, of eletcrically conductive metal such as gold and a layer **23** of hafnium nitride. Conductive terminals **21***a* and **21***b* are not essential but are customarily employed in the construction of printed circuit boards. With reference once again to the example under discussion, the substrate is maintained at temperatures within the range of 300–500° C. during the reactive sputtering process. Following the deposition technique, the hafnium nitride film is heated to a temperature within the range of 250–400° C. in the presence of air, thereby stabilizing the nitride film. Electron diffraction studies indicate that reactively sputtered hafnium nitride films have porperties suitable for resistor purposes and, when produced in accordance with the techniques described herein, are of a face-centered cubic structure (HfN).

Several examples of the present invention are described in detail below. These examples and the illustration described above 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 fabrication of a hafnium nitride resistor in accordance wtih the persent inventive technique.

A sputtering apparatus similar to that shown in FIG. 1 was used to produce the hafnium nitride layer. The cathode consisted of a circular hafnium disk 10 centimeters in diameter of high purity. In the apparatus actually employed, the anode was grounded, the potential difference being obtained by making the cathode negative with respect to ground.

A glass microscope slide, approximately 1" in width and 3" in length was used as a substrate. Nichrome gold terminals were evaporated on each longitudinal side of the substrate. The terminated slide was then cleaned using the following procedure. Initially, the slide was washed in a detergent to remove large particles of dirt and grease. Next, there followed a tap water rinse, a 10 minute boil in a 10 percent hydrogen peroxide solution, a distilled water rinse, a 10 minutes boil in distilled water, and storage in an oven maintained at 150° C. until ready for use.

The vacuum chamber was evacuated by means of an oil diffusion pump to a pressure of approximately 5×10^{-6} torr. after a time period within the range of 15 to 45 minutes. Next, the substrate was heated to a temperature of approximately 400° C. at which point nitrogen was admitted into the chamber at a dynamic pressure, and, after attaining equilibrium, argon was admitted into the chamber at a pressure of approximately 20×10^{-3} torr. During the sputtering reaction, the partial pressure of the nitrogen was maintained at approximately 2×10^{-3} torr.

The anode and cathode were spaced approximately 2½" apart, the cleansed substrate being placed therebetween at a position immediately with the Crooke's Dark Space. The substrate was maintained at a temperature of 350° C. during the sputtering reaction. A D-C voltage of 4000 volts was impressed between cathode and anode at a current density of 0.43 milliampere per square centimeter. In order to establish equilibrium when first beginning the sputtering operation, it was found helpful to sputter on a shield for several minutes thereby issuing reproducible results. Sputtering was conducted for approximately 8 minutes, resulting in a layer of approximately 1100 A. in thickness.

Following the sputtering treatment, the resistance in ohms and specific resistivity in microhm-centimeters was measured. Next, the sputtered resistor was heated in air for 1 hour at a temperature of 425° C. The device so fabricated was again measured to determine its resistance. Stability of the resistor was determined by power aging at 1 volt for approximately 1000 hours. The results are set forth in the tabel below together with the results obtained by repetition of the foregoing procedure. Each of the results set forth in the table is to be considered as an independent example.

TABLE

	F.T. in A.	PN_2 in torr.	Initial R in ohms	Res. in ohms after heat treat.	ΔR 90 (425° C.) after— 24 hrs.	108 hrs.	504 hrs.	1,008 hrs.
(1)	1,100	2×10^{-3}	2,705	2,789	0.118	0.191	0.225	0.228
(2)	1,100	2×10^{-3}	2,442	2,518	0.106	0.182	0.218	0.265
(3)	1,100	2×10^{-3}	2,472	2,549	0.122	0.193	0.239	0.290
(4)	1,100	2×10^{-3}	2,576	2,656	0.113	0.181	0.225	0.270
(5)	1,100	2×10^{-3}	3,519	3,628	0.102	0.153	0.168	0.230

F.T.=Film thickness.
PN_2=Partial pressure of nitrogen.

Analysis of the data set forth in the table indicates that the resistance of the hafnium nitride films prepared in accordance with the invention are appreciably enhanced by the heat treatment, so producing a uniquely stable resistor as noted from the aging data. Furthermore, as may be seen by reference to FIG. 2, the hafnium nitride films manifest resistivities ranging from 150–1000 microhm-centimeters over the nitrogen partial pressure range of interest herein, whereas the temperature coefficient of resistance over this range varies from +500 to −500 parts per million per degree centigrade. This behavior is superior to that of tantalum nitride which shows only modest changes in resistivity and temperature coefficient of resistance over the nitrogen partial pressure ranges employed in the fabrication of such structures.

While the invention has been described in detail in the foregoing specification, and the drawing similarly illustrates the same, the aforesaid is by way of illustration only and is not restrictive in character. It will be appreciated by those skilled in the art that the novel resistors may be fabricated by methods other than reactive sputtering; such methods being well known by those skilled in the art. The several modifications which will readily suggest themselves to persons skilled in the art are all considered within the scope of the invention, reference being had to the appended claims.

What is claimed is:

1. A stable metal film resistor evidencing a resistivity ranging from 150 to 1000 microhm-centimeters over a range of temperature coefficients of resistance of from +500 to −500 parts per million per degree centigrade including a non-conducting substrate, a thin film consisting essentially of hafnium nitride and a pair of spaced electrical leads attached to said film.

2. Resistor in accordance with claim **1** wherein said film consists essentially of hafnium nitride of cubic structure.

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U.S. Cl. X.R.

117—201; 338—334