

[54] CYLINDRICAL RF SPUTTERING
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3,855,110.

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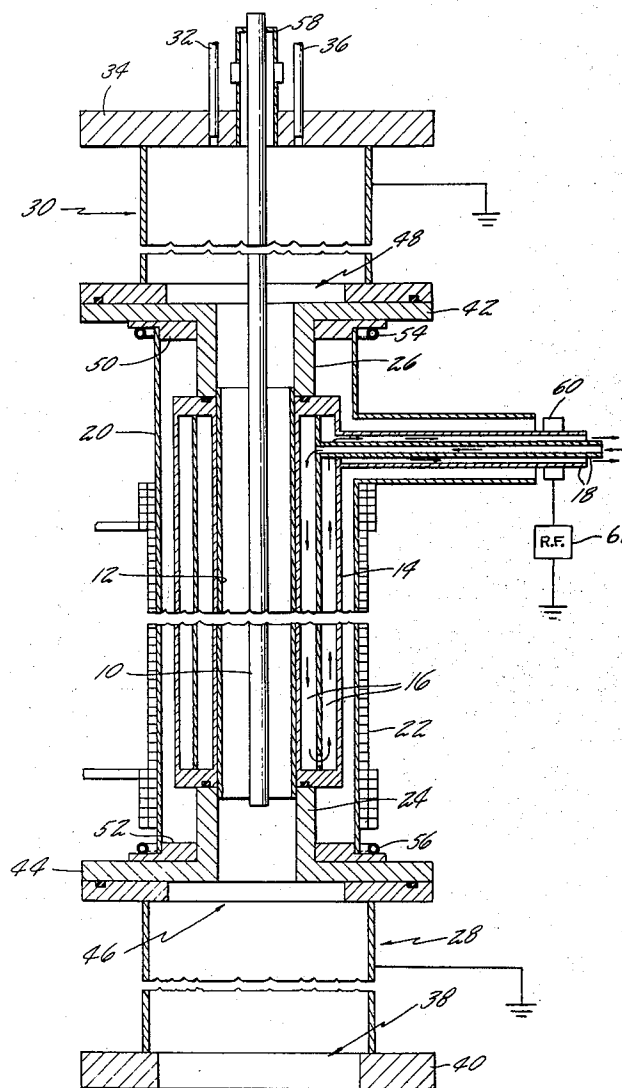
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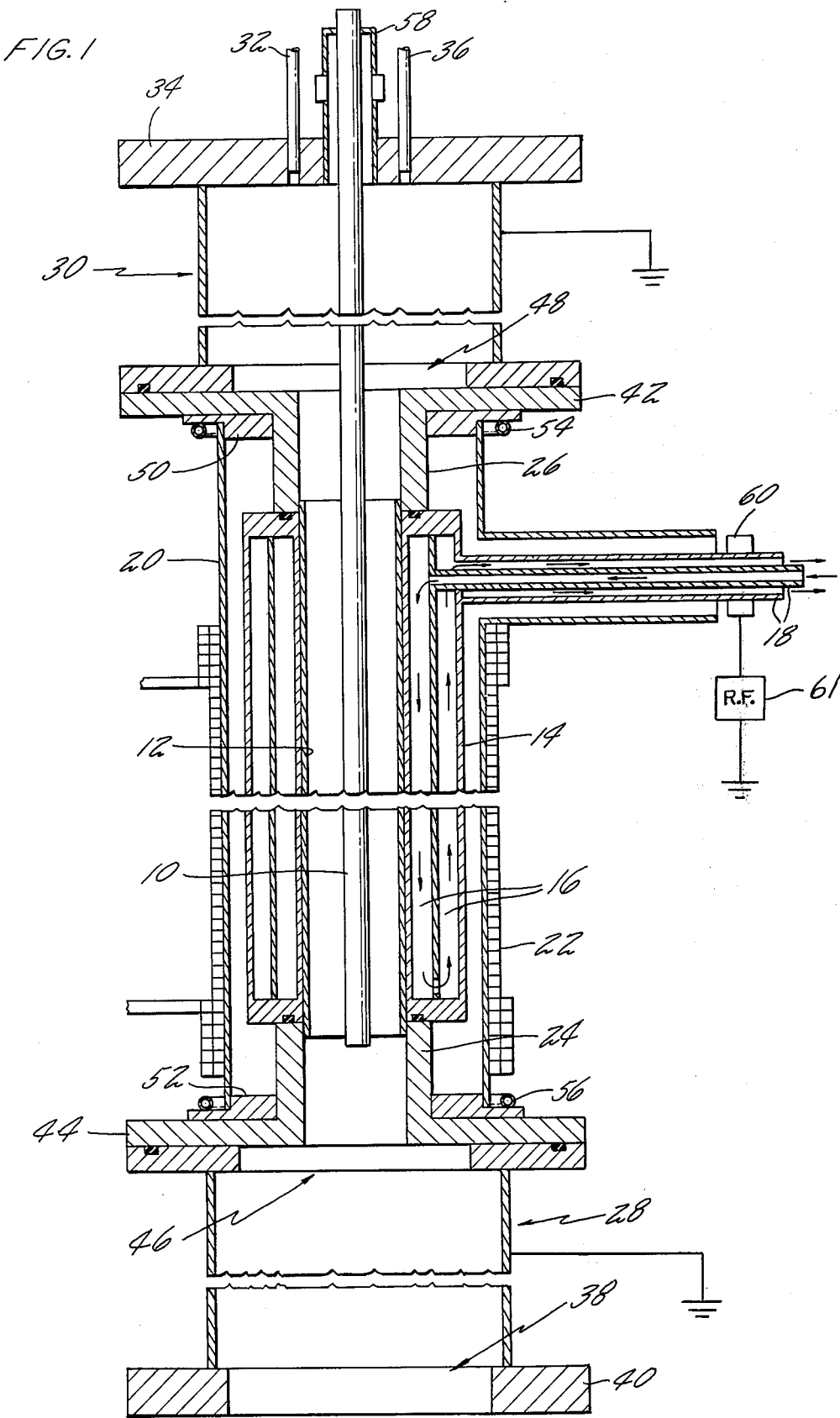
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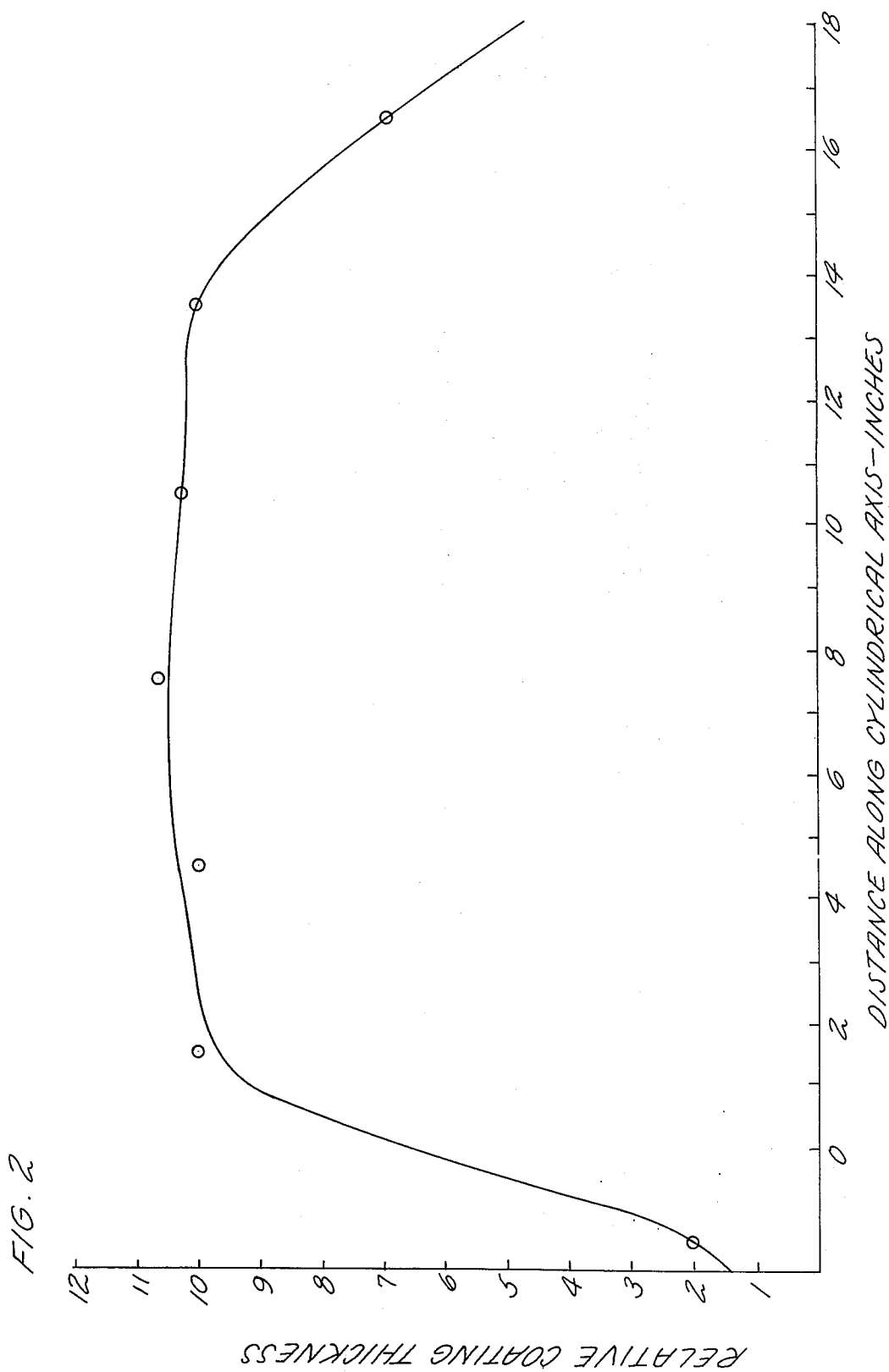
ABSTRACT

A cylindrical cathode is used as a vacuum chamber to permit sputtering by means of rf potential on all sides of a workpiece located coaxially within the chamber. Both insulators and conductors may be used as target materials and as workpieces. Even deposition of the sputtered material on long or continuously fed workpieces is achieved by properly terminating the ends of the coaxial sputtering chamber with grounded chambers of larger diameter than the sputtering chamber and of sufficient length to thereby gradually reduce the plasma density along the axial direction to a relatively small value before reaching the end walls.

4 Claims, 2 Drawing Figures







CYLINDRICAL RF SPUTTERING APPARATUS

This is a division of application Ser. No. 416,318 filed Nov. 15, 1973, now U.S. Pat. No. 3,855,110.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to high rate sputtering apparatus for depositing films of material on a substrate. More specifically this invention relates to an improved sputtering apparatus which permits insulators as well as conductors and semiconductors to be deposited on the entire surface of any workpiece without the need for rotating the workpiece. In another aspect this invention relates to an improved method and apparatus for sculpturing the plasma density in a chamber.

2. Description of the Prior Art

Prior to the present invention, the coating of workpieces by sputtering was generally limited to coating only one side at a time, or to coating all sides by sputtering outwardly from either a planar or cylindrical target onto a rotating workpiece. Electrically conducting materials but not insulating materials can presently be applied to a workpiece using dc energization only by sputtering inwardly toward the workpiece from a cylindrical target.

Coating a workpiece by rotating the workpiece in front of a sputtering target is limited in its applicability since the workpiece must be sufficiently strong to withstand the mechanical forces produced by the rotation, and thus only relatively small, sturdy workpieces can be utilized. Another disadvantage of this technique is that the workpiece is thermally cycled as it rotates, thereby causing additional stress and mechanical problems. Complicated mechanical apparatus is also necessary to introduce the rotary motion into the sputtering chamber, and this requirement raises additional difficulties when connections to the workpiece or sputtering chamber are desired. For example, it may be necessary to introduce water cooling to the workpiece, or to monitor the temperature with a thermocouple, or provide bias sputtering of the workpiece to promote good coating adherence.

SUMMARY OF THE INVENTION

The present invention avoids the limitations of the prior art by allowing the use of rf energization to sputter inwardly from a cylindrical target. This eliminates the need for rotating the workpiece and permits a workpiece to be coated on all sides by conducting or insulating materials. By means of the present invention, it is also possible to coat workpieces of considerable length or continuously fed workpieces.

In accordance with the present invention, a cylindrical target electrode is used as a portion of the vacuum chamber and an rf field applied to the low pressure gas in the chamber to form a plasma therein. The workpiece which may be a long, narrow rod or fiber is located on or near the axis of the cylinder. To permit the even deposition of the target material axially along the workpiece, the ends of the cylindrical vacuum chamber are modified by providing grounded chambers with dimensions sufficiently large to allow the plasma density to decay gradually. The end chambers are electrically isolated from the target electrode chamber, and the target electrode is surrounded by a cylindrical electro-

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical section showing the preferred structure of the sputtering apparatus.

FIG. 2 shows in partial graph form the axial variation in thickness of deposited material on a workpiece using the structure of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, there is shown a substrate or workpiece 10 in the form of a long rod. The workpiece may be composed of either an insulating or conducting material and may be of any shape compatible with the sputtering apparatus to be described.

Surrounding the workpiece 10 is the cylindrical target 12 composed of the material with which it is desired to coat the workpiece, and which for purposes of this invention may be a conductor, semiconductor or insulator. The target 12 is affixed to a cylindrical cathode member 14 of conductive or metallic material, the cathode member 14 also serving as a support and a heat sink for the target 12. The target 12 may be attached to the cathode member 14 by any known means such as soldering to assure efficient heat and electrical power transfer. As shown in the figure the cathode member 14 contains passages 16 through which water is circulated to cool the walls of the cathode member 14. The water is pumped into and extracted from the passages 16 via conduit 18.

The target and cathode assembly are surrounded by a shield 20 of copper or other suitable material for purposes of radiation protection. An electromagnet 22 in the shape of a cylinder surrounds the shield 20 outside of the cathode and provides an axial magnetic field which promotes uniform plasma formation along the axis of the cathode, stabilizes the plasma, and provides a degree of temperature control of the object to be coated. The axial magnetic field, however, is not essential to operation of the sputtering apparatus, but merely enhances its operation.

Apparatus of the type described above has been used to apply a coating of a conductive material to a workpiece by forming the target of the conductive material which it is desired to sputter onto the workpiece and applying a dc voltage to the target electrode. When a radio frequency (rf) potential was applied, however, to the target electrode, uneven coating of the workpiece resulted, and large voltages were induced on the workpiece which resulted in sputtering of the workpiece material onto the cylindrical target. It was theorized that the erratic operation was caused by the reflection of the rf waves from the high plasma density gradient which appeared at the ends of the chamber. It was further speculated that by gradually reducing the gradient of the plasma density, the reflections would not occur and improved operation would result. By terminating the ends of the cathode chamber with grounded cylindrical chambers of larger diameter than the cathode chamber and having dimensions large enough to allow the plasma density to decay to a relatively small value before reaching the walls of the end chamber, it has been found that radically improved operation of the sputtering apparatus occurs, and that with the use of rf potentials both insulating and conducting materials may be coated on the workpiece.

Referring again to FIG. 1, a preferred embodiment of the improved apparatus is shown. To each end of the cathode member 14 there is attached a cylindrical insulating standoff shown at 24 and 26. Onto each insulating standoff is attached a cylindrical termination chamber shown at 28 and 30 formed from a metallic material such as stainless steel. A gas inlet 32 as well as a gas pressure gauge port 36 are provided in end cap 34 of termination chamber 30, while a gas pumpout port 38 is provided in end cap 40 of termination chamber 28. The electrically grounded termination chambers are attached to the insulating standoffs 26 and 24 by plates 42 and 44 preferably of insulating material, each plate containing an opening in the center thereof as shown at 46 and 48. O-ring seals are used between the termination chambers 28 and 30 and the respective insulating plates 44 and 42, and also between the cathode 14 and insulating standoffs 24 and 26. Heat sinks 50 and 52 are shown positioned in contact with insulating standoffs 24 and 26, the heat sinks being cooled by cooling coils 54 and 56. An insulated workpiece holder is shown at 58, and an R.F. source 61 is shown connected at 60.

Typical operation involves loading a clean workpiece 10 into the cylindrical sputtering chamber as shown in FIG. 1. The chamber is then evacuated to about 10^{-6} torr. A gas, generally but not necessarily inert, is next admitted to the sputtering chamber to a pressure of about 10^{-2} torr. A dc axial magnetic field of about 150 gauss is imposed in the cylindrical cathode cavity. With cooling water flowing, the desired rf power density is applied to the cathode. If sputter cleaning or bias sputtering of the workpiece is desired, the workpiece is electrically connected to a lead of the insulated feed through 58, and a bias potential of either rf or dc is applied. An rf bias would be required if the workpiece were being coated with an insulator. A special feature of this cylindrical cathode is that a self-induced rf bias will appear on the workpiece if the insulated feed through lead is externally connected to ground. The magnitude of the self-induced bias can be decreased by adding electrical resistance between the lead and ground.

An example of a preferred embodiment of the apparatus has a target 15 inches long and 2.5 inches in inside diameter, with termination chambers 6 inches in diameter and 10 inches long. With applied rf power densities of 8.6 w/in.² to 25 w/in.², coatings were applied successfully to fibers of a 0.004 inch diameter as well as rods of 0.5 inch diameter. Sputtering targets were of insulating as well as conducting materials, and coatings were applied to insulating as well as conducting workpieces. For example, a coating of Al₂O₃ has been applied to a workpiece of tungsten at a rate of 85A./min., and a coating of Ni has been applied to a workpiece of alumina at a rate of 750A./min., both coatings being applied with a power input of 8.6 w/in.² with an rf frequency of 13.56 MHz.

To illustrate the effect of the use of the terminating chambers on a workpiece, FIG. 2 shows in graph form a typical coating thickness profile for workpieces placed along the axis of the cylindrical target. The coat-

ing thickness is substantially uniform along the length of the workpiece.

It is apparent that the apparatus described may be made larger or smaller by varying the diameter and/or the length of the cathode chamber. The cathode chamber length, however, must be short compared to a quarter wavelength of applied rf potential, or several sections may be connected in line to achieve the desired length. Each section, by itself, must be less than a quarter wavelength and electrically isolated from the other cathode chambers. This isolation could be achieved by the use of insulating standoffs and grounded end chambers. By connecting the chambers in line, a continuous feeding of a long workpiece through the chambers is possible.

Other variations of the chamber construction may be used to gradually reduce the plasma density at the desired rate at the end walls. For example, external electric or magnetic fields may be used separately or in combination to sculpture the plasma to any desired density gradient along the axial length of the chamber. In some applications it may be desired to coat a workpiece in an irregular manner, or to use a termination chamber at one end of the chamber only. In other applications it may be desired to utilize the reflections of the rf energy from the plasma density gradient for irregularly shaped workpieces.

Other modifications of the structure and operation of this invention will be apparent to those skilled in the art.

We claim:

1. A method for uniformly coating a workpiece contained along the axis of a cylindrical workpiece chamber by sputtering onto said workpiece a coating from a target material, said workpiece chamber being defined by a cylindrical metal electrode adapted to support said target material on the inner circumference thereof, comprising the steps of

filling said workpiece chamber with a gas at a low pressure,

applying a source of rf potential to said electrode to generate a plasma in said workpiece chamber, and reducing the plasma density gradient at the ends of said workpiece chamber by terminating each end of said workpiece chamber with an electrically grounded metal cylindrical termination chamber which is electrically insulated from said workpiece chamber and is of greater cross-sectional area than the cross-sectional area of said workpiece chamber, each said termination chamber having an aperture therein aligned with said workpiece chamber to permit expansion of said plasma into said termination chamber.

2. The method of claim 1 in which said target material is an electrical conductor.

3. The method of claim 1 in which said target material is an electrical insulator.

4. The method of claim 1 including the step of adjusting the frequency of said source of rf potential so that the axial length of said workpiece chamber is short relative to a quarter wavelength of said rf potential.

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