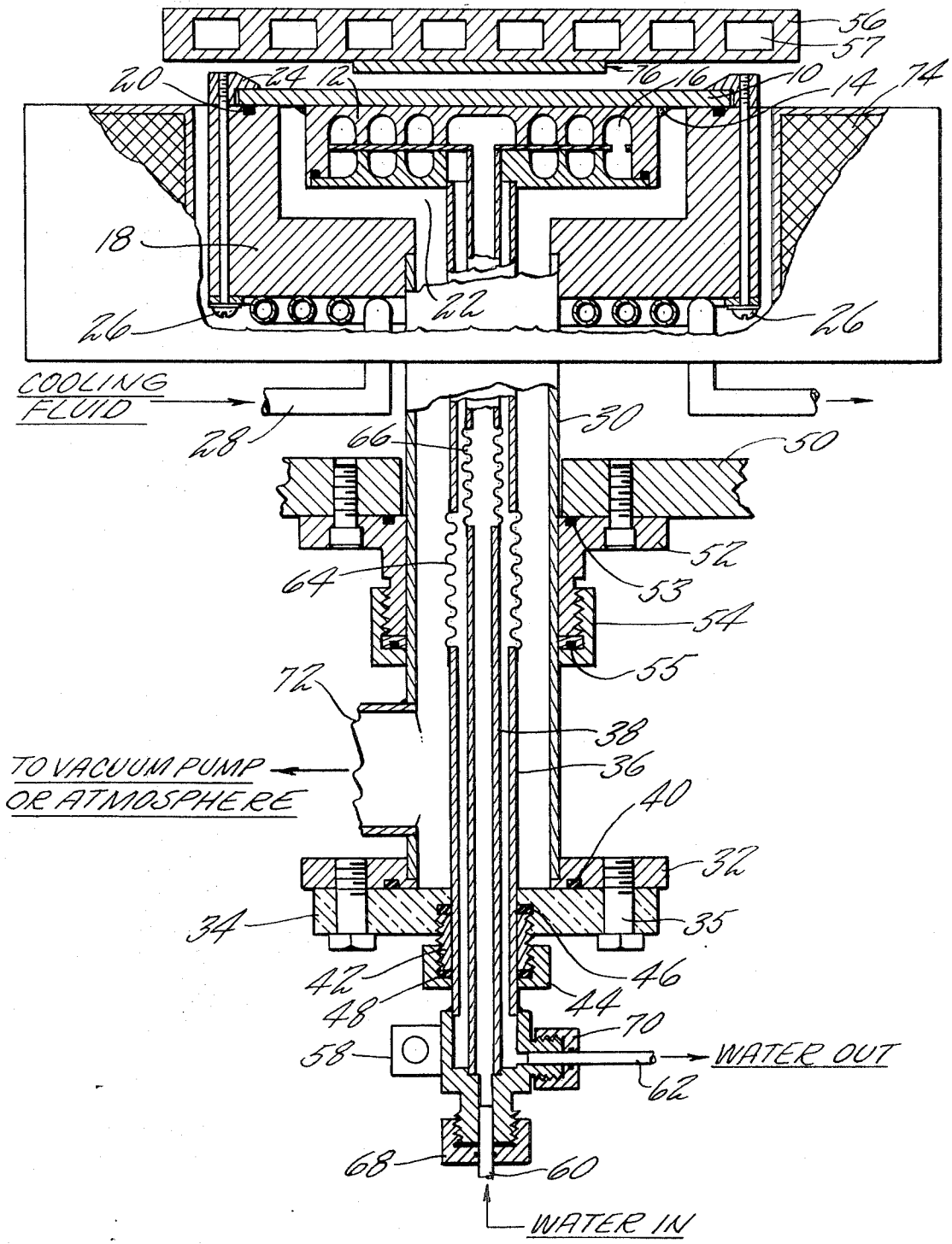
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SPUTTERING APPARATUS WITH SEALED CATHODE-SHIELD CHAMBER

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SPUTTERING APPARATUS WITH SEALED CATHODE-SHIELD CHAMBER

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ABSTRACT OF THE DISCLOSURE

Films of material are deposited on a substrate at high rates by sputtering in which a target is bombarded by ions in a low pressure glow discharge in the presence of a magnetic field. A very low pressure is provided by a vacuum pump in a sealed chamber between the cathode and the ground shield to prevent arcing at high power densities. Atmospheric pressure may also be admitted to the sealed chamber.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to a high rate sputtering apparatus for depositing films of material on a substrate. More specifically, this invention relates to a sputtering apparatus for conducting, semiconducting and insulating materials in which high power densities may be applied to the material to increase the rate of sputtering. A sealed chamber is provided between the cathode electrode and its associated ground shield which may be evacuated by a vacuum pump to prevent arcing and breakdown between the cathode and the ground shield. Atmospheric pressure may also be admitted to the sealed chamber. A magnetic field having a high radial component may be applied to the target to increase the rate of sputtering.

Description of the prior art

U.S. Pat. No. 3,369,991 describes an apparatus for cathode sputtering of solid dielectric materials including a shielded RF electrode. An important feature of the patent is the spacing provided between the exposed surface of the target electrode (cathode) and its shield. More specifically, the patent states that when the spacing lies within a certain critical range, an optimum condition is achieved whereby the radio-frequency capacitive coupling between the electrode and its shield is low enough to be disregarded, yet there is no perceptible tendency to sputter metal or other contaminants from the electrode. The spacing has a lower limit of about one-quarter inch and an upper limit not greater than the Crooks dark space in the glow discharge. Thus the radio-frequency sputtering of dielectrics must be accomplished with gas pressure no greater than about 30 microns. A typical example uses 5 microns pressure in argon gas.

A further feature disclosed in the prior art patent is the application to the gas in the ionization chamber of a steady magnetic field to enhance the ionizing action. The magnetic field is applied normal to the surface of the target.

However, with the apparatus as described in the prior art patent, the application of high magnetic fields and large voltages in order to increase the sputtering rate results in an arc breakdown at the cathode. The sputtering rate is limited by the high voltage breakdown of the low pressure gas between the electrode and the grounded shield in proximity to it.

From Paschen's law it is known that gaseous breakdown voltages pass through minimum values and then begin

to increase rapidly as the *pd* product decreases, where *p* is the gas pressure and *d* is the electrode to ground shield spacing. The arc breakdown problem at high power densities cannot be overcome by an arbitrary reduction in the *pd* product by decreasing the spacing *d* between the electrode and the shield because of the fabrication tolerances and the onset of other breakdown mechanisms such as field emission from microscopic irregularities in electrode and shield surfaces. Furthermore, with too close coupling between the electrode and the ground shield, excessive RF power would be lost to ground.

SUMMARY OF THE INVENTION

It is therefore a primary object of this invention to increase the rate of sputtering of conducting, semiconducting and insulating materials in a sputtering apparatus by preventing arc breakdown between the cathode electrode and its shield at high power densities.

In accordance with the present invention, a sealed chamber is formed between the cathode electrode and its grounded shield through the use of appropriate seals, and the chamber is evacuated by a vacuum pump to a pressure below about 5×10^{-5} torr. This reduces the *pd* product in the annular space around the cathode and permits power density inputs to the target of 850 watts/in.^{2} and above.

In accordance with another aspect of the present invention, a gas at or about atmospheric pressure may be admitted to the sealed chamber between the target electrode and the ground shield. This places the operating conditions in a higher voltage breakdown region above the minimum value on Paschen's curve.

In accordance with a further aspect of this invention, a high properly vectored magnetic field is applied to the target to increase the plasma density and optimize the sputtering rate. An electromagnet in the shape of a toroid surrounds the target and produces a magnetic field at the target which has both axial and radial components with respect to the target, thereby increasing the electron path length between the electrodes and increasing the collisional probability.

The sealed chamber and the magnetic field are applicable to all types of targets, and to embodiments in which either DC or RF electric fields are applied between the electrodes.

BRIEF DESCRIPTION OF THE DRAWING

The figure is a vertical section showing the shielded electrode structure of a dielectric sputtering apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A general description of the process of sputtering a dielectric material and coating the dielectric upon a sample may be found in U.S. Pat. 3,369,991. This patent also describes the problems which arise when it is attempted to shield the target electrode from bombardment by the gas ions. This prior art patent teaches that a space is provided between the exposed surface of the target electrode and its shield, the spacing lying within a certain critical range whereby the RF capacitive coupling between the electrode and its shield is low enough to be disregarded, yet there is no perceptible tendency to sputter metal or other contaminants from the electrode.

The apparatus described in this prior art patent has been found to be deficient at high power densities and high magnetic fields when it is attempted to increase the rate of sputtering. The deficiency involves the breakdown and arcing of the gas in the space between the target electrode and the shield.

In order to overcome this deficiency, this invention provides a closed chamber between the target electrode and its shield. In the preferred embodiment this chamber is

evacuated to a very low pressure. The space between the target electrode and the shield is therefore not open to the higher gas pressures in the sputtering chamber. By lowering the gas pressure, much higher power densities and magnetic fields may be maintained and the rate of sputtering increased by a factor of about 10.

In another embodiment of this invention, the sealed chamber between the target electrode and its shield has admitted thereto a high pressure gas at about atmospheric pressure or slightly above. This embodiment allows for the application of higher electric and magnetic fields at the target than the prior art, but not as high as when the sealed chamber is evacuated to a very low pressure. The advantage of using the high atmospheric pressure is that the apparatus is simpler and less expensive than in the evacuated embodiment.

The invention will be described in its preferred embodiment as using a dielectric target in a configuration which requires RF electric fields, but it will be apparent to one skilled in the art that other types of targets such as conducting and semiconducting may be used, and likewise that either DC or RF electric fields may be used.

Referring to the figure there is shown a vertical section view of the shielded electrode structure of this invention. A low porosity dielectric target **10** is mounted on the cathode electrode **12**. The electrode **12** is preferably brazed in one piece to prevent bowing of the front surface. A soft solder seal **14** is provided at the interface between the target **10** and the cathode **12**. The cathode **12** contains chambers **16** through which a cooling fluid may be distributed as will be described.

Surrounding the cathode **12** is a ground shield **18** of metallic material having an upwardly extending annular lip portion that fully encloses the cathode **12**. An O ring **20** is inserted between the metallic shield **18** and the target **10** to provide a vacuum seal for chamber **22** between the shield **18** and the cathode **12**. The shield **18** is maintained at ground potential.

The target **10** is maintained in its position by a sealing ring or flange **24** which is fixed in position by bolts **26** extending through shield **18**.

Ground shield **18** is cooled by a plurality of cooling coils **28** through which a cooling fluid is distributed from a fluid source (not shown).

Shield **18** is supported by one end of a grounded post **30**, the post being supported at its other end by an annular metallic ring **32** which is electrically connected to ground. Connected to metallic ring **32** is an insulating ring **34** whose purpose is to center and support metal tube **36** and tube **38** concentric with tube **36** through which cooling fluid flows to cathode **12**. An O ring seal **40** is positioned between metallic ring **32** and insulating ring **34**.

Metallic ring **32** and insulating ring **34** are maintained in rigid position relative to each other by bolts **35**. Seal **40** is compressed thereby to effect a vacuum seal for chamber **22**. Threaded metal sleeve **42** centers tubes **36** and **38** with respect to post **20**, and exerts pressure on O ring seal **46** to provide vacuum sealing of chamber **22** when ferrule **44** with its seal **48** are threaded onto sleeve **42**.

A low pressure gas ionization chamber is provided for the sputtering operation by a wall **50** in the form of a bell jar made of a suitable material. Access to the chamber is gained by penetrating the wall **50** and effecting a vacuum seal by means of a flange **52** which is sealed by seal **53**. Flange **52** is threaded at one end and is supported by a ferrule **54** sealed at **55**.

Inserted in the low pressure ionization chamber is an anode **56**, having cooling passages **57**. A radio-frequency voltage is applied between anode **56** and cathode **12** from an RF source, not shown, which is connected to the cathode through lug or terminal **58**. The other side of the RF source is connected to anode **56** by any suitable means.

Terminal **58** is in electrical contact with cathode **12** through metal tube **36**. Insulating ring **34** maintains electrical insulation between the cathode voltage and the voltage of the grounded shield **18** and metal post **30**.

A cooling fluid is flowed through tube **38** to cathode **12** through an input tube **60**. The cooling fluid flows through chambers **16** within the cathode and is returned through tube **36** and outlet tube **62** to a reservoir.

Bellows **64** and **66** are provided in the lines of tubes **36** and **38** to prevent stress on target **10** from misalignment in the final assembly and the expansion and contraction caused by the high power operation and heating of the apparatus.

Threaded ferrules **68** and **70** sealed by gaskets are provided to support lines **60** and **62** at the inlet and outlet for the cooling fluid.

The sample **76** to be coated may be located between anode **56** and cathode **12**, and preferably is in contact with anode **56**. The coating takes place in the ionization chamber at reduced pressures and in suitable gas atmosphere as is known to those skilled in the art.

In the preferred embodiment of this invention, a vacuum pump, not shown, is connected with chamber **22** through an opening **72** in the wall of post **30**. The pressure in sealed chamber **22** is reduced to a value below about 5×10^{-5} torr by the vacuum pump. At this pressure there is no breakdown between the cathode **12** and the shield **18** at power densities of approximately 850 watts/in.^{2}. By virtue of the sealing arrangement shown, chamber **22** may be maintained in a highly evacuated condition since it is not in contact with either atmospheric pressure or with the fairly low pressure within the ionizing chamber in which the sputtering is performed.

Alternately, the sputtering apparatus may be operated by admitting high pressure gas into the chamber **22**, the gas being at atmospheric pressure or slightly above. In this mode of operation the device operates on the high *pd* portion of the Paschen curve in a high breakdown region. The preferred gases are SF_6 and some of the Freons. Air may also be used. As indicated previously, this mode of operation will allow for the application of higher electric and magnetic fields at the target than the prior art, but it will not allow for application of as high fields as the evacuated mode of operation. However, the elimination of the vacuum pump allows simpler and less expensive construction.

Although the invention has been described in terms of a dielectric or an insulating target, the invention may also be used with conducting metals and semiconducting targets by adding electrical insulation between the metal or dielectric target and the ground shield. Appropriate sealing is also necessary. In these embodiments, either DC or RF electric fields may be used depending upon the preferred configuration. With metallic targets, a portion of the shield may be made from insulating material such as Al_2O_3 for DC operation.

Regardless of the configuration, operation may be enhanced by surrounding the cathode and cathode shield with an electromagnet **74** in the shape of a toroid. The exact position of the electromagnet **74** in the axial direction and its precise size may be varied somewhat depending on the mode of operation of the sputtering apparatus. Optimum coupling between the magnetic field and the electric field between the cathode and anode is desired. It is important that the magnetic field have a high radial component so that the electron path length between the cathode and anode electrodes may be increased. For some modes of operation it is desirable that the radial component of the magnetic field be about the same order of magnitude as the axial component of the magnetic field. The reason for the magnetic field is that at pressures of between about 4 and 12 microns, electron mean free paths are on the same order of magnitude as the electrode separation. Therefore, to increase the probability of collision, the electron path length between the electrodes is increased

by the radial field as the electrons are accelerated toward the anode by the electric field. The axial component of the field tends to prevent the escape of those electrons which have a radial velocity component.

Another important aspect of this invention is that the metal cathode **12** is bonded to the target material **10** with an appropriate solder **14**, and the cathode **12** is cooled by water or some other fluid in order to keep the target temperature uniform and to avoid cracking. Flange **24** around the target **10** is designed to avoid torsional stress in the target, which, coupled with the temperature gradient through the target, has in the past caused cracking at relatively low power densities.

Sputtering rates have been increased considerably by use of the apparatus described. Power densities using RF fields have been raised to approximately 850 watts/in.^{2} and above at high RF frequencies with the pressure in the chamber **22** lowered to 5×10^{-5} torr and below. Rates of deposition for representative materials are: Al_2O_3, 6,300 angstroms per minute; for SiO_2 (quartz), 10,000 angstroms per minute.

It is to be understood that the invention is not limited to the specific embodiment herein illustrated and described but may be used in other ways without departure from its spirit as defined by the following claims.

We claim:

1. In an apparatus for coating samples with material sputtered from a target, and including:

a low pressure gas ionization chamber adapted to contain the target and the sample to be coated,

means for applying an electric field between first and second electrodes in said ionization chamber for ionizing said gas and maintaining a glow discharge, said target being supported by said first electrode and being mounted substantially between said electrodes,

and a grounded shield surrounding said first electrode,

the improvement comprising a sealed chamber between said first electrode and said shield, a portion of said sealed chamber being formed by said target,

and means for maintaining a preselected gas pressure in said sealed chamber to prevent breakdown between said first electrode and said shield.

2. Apparatus as in claim **1** and including means for applying a magnetic field to the ionized gas in said ionizing chamber.

3. Apparatus as in claim **2** in which said magnetic field has a first component in the direction normal to said target, and a second component in the direction at right angles to said first component, said two components being approximately equal.

4. Apparatus as in claim **2** in which said means for applying a magnetic field is a toroidal electromagnet positioned substantially adjacent said target.

5. Apparatus as in claim **1** and including means for evacuating said chamber to a pressure much lower than the pressure in said ionization chamber.

6. Apparatus as in claim **1** and including means for pressuring said chamber with a gas at about atmospheric pressure.

7. Apparatus as in claim **1** in which said means for applying said electric field is a DC source.

8. Apparatus as in claim **1** in which said means for applying said electric field is a RF source.

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