ABSTRACT: The invention eliminates the drawbacks of the prior methods for cathode-sputtering deposition by providing basically the use of a substantially neutral plasma adapted to be carried in the form of a stable parallel beam to a substantial distance from the source without resorting to intricate electrode arrangements.
PRODUCTION OF DEPOSITS BY CATHODE SPUTTERING

BACKGROUND OF THE INVENTION

The invention relates to improvements to the method whereby a deposit in thin-layer form can be obtained by cathode sputtering. The invention also relates to the devices for carrying such improvements into effect.

It has for long been proposed to use the cathode sputtering phenomenon for producing deposits onto objects or substrates.

The most ancient methods of this type consisted in using a cathode made of the material to be sputtered and in depositing said material onto anode through a conducting medium consisting of an inert gas which was ionized by the electrons travelling from the cathode to the anode. Such methods involved high power consumption since they used a cold cathode, so that voltages of several thousand volts were required to produce satisfactory electron flow between the cathode and anode. Moreover, this type of discharge required a rather high gas pressure (from 10 to 100 microns Hg).

An initial improvement to the prior art, which afforded a reduction in the power necessary to provide the ion flow, was the use of a hot cathode. As a matter of fact, an electron-accelerating voltage of less than 100 volts across the anode and cathode is then sufficient for extraction of the electrons. In such a system, the source of gas-ionizing electrons and the source of material to be sputtered are distinct. The material being sputtered is removed from a target which is bombarded by the ions formed between the cathode and anode, said ions being accelerated by said target.

To further increase the electron density within the gas to be ionized, a further prior art proposal was to place a tubular anode in front of a filament heated to a high temperature and to establish within the tubular anode a magnetic field parallel to the axis of said tubular anode, the electrons and ions formed being then caused to follow helical paths around the electrode axis, while a still further increase in the degree of gas ionization was provided by locating near the tubular electrode a second electrode of annular shape, also called extraction electrode, at a negative potential with respect to the tubular electrode. This extraction electrode acts to repel the electrons towards the tubular electrode and to direct the ions towards the target. The result is an excellent electron concentration in the interior of the tubular electrode and a high-density electron flow at the outlet of the second electrode. However, the resulting ion flux tends to be divergent and further electrodes must be so arranged as to render it parallel or convergent. Consequently, the devices for carrying such a method into effect become intricate, all the more as the voltages and relative positions of the electrodes are to be carefully controlled.

SUMMARY OF THE INVENTION

The purpose of the invention is to eliminate the drawbacks of the prior methods for cathode-sputtering deposition, mainly by providing the use of a substantially neutral plasma which can be carried in the form of a stable parallel beam to a rather great distance from the source without resorting to intricate electrode arrangements.

According to the invention, the method for producing a thin-layer deposit onto an object by cathode sputtering, the material to be sputtered being taken from a target, consists basically in establishing in vacuo at some distance from said target a substantially neutral plasma in pencil form by ionizing an inert gas by means of a diaphragm-delineated beam of electrons issuing from a heated filament and by subjecting said electrons to the concurrent action of an electric field which is created by a tubular anode located adjacent said diaphragm, and of a magnetic field which extends parallel to said anode axis, and in so arranging said target, which is at a negative potential, that said plasma pencil will lie level with the surface thereof, said object to be coated standing in close vicinity and opposite to said surface.

2 An advantageous feature of the method of the invention is that the substantially neutral plasma can be formed within one compartment of the vacuum chamber and the target be arranged in another compartment, which may be under higher vacuum. It is easy to extract the positive ions from the plasma and to accelerate these for directing them onto the target by bringing said target to a negative potential of some hundreds volts.

Part of the electrons emanating from the filament and passing through the diaphragm aperture are not confined within the tubular anode and become mingled with the positive ion flow, e.g., argon ion flow, thus providing outside the tubular electrode a substantially neutral plasma comprised of electrons and positive ions. This plasma is shaped into a pencil or beam of low transverse dimension.

The electrons which are confined within the tubular anode are set in known manner into helical motion under the simultaneous action of the electrostatic field created between the filament and the tubular anode, which is at a positive potential with respect to the filament, and of the magnetic field which lies parallel to the tubular anode and is magnetically generated by a coil external to the vacuum chamber.

When the method according to the invention is carried into effect in a vacuum chamber including two compartments, then the compartments where the plasma is formed is connected to the target-containing compartment through an aperture of a low size sufficient to allow free passage of the plasma beam.

Thus, the invention affords operational facilities which are an advance over the prior art. According to the invention, the rate of deposition can reach a few tens of microns per hour, while the prior methods allowed but for deposition rates of some 2–3 μ/hour.

The material used for sputtering may be silver, nickel, titanium, tantalum or other materials useful for thin-layer deposition. The objects to be coated may be any articles especially insulated parts for the production of thin-layer circuits. The inert gas used to form the plasma is advantageously argon.

BRIEF DESCRIPTION OF THE DRAWINGS

Two devices for carrying the method of the invention into effect will now be described by way of examples with reference to the accompanying drawings which are diagrammatic views in axial section, of which:

FIG. 1 shows the first device;
FIG. 2 shows the second device, which is to be preferred in practice.

DETAILED DESCRIPTION

In FIG. 1, there is shown at 1 a vacuum vessel and reference 2 designates a filament which is brought by resistance heating through wires 2a, 2b to a temperature of 2,000–2,800 °C. Filament 2 is arranged within a bent tube 3, cooled by water circulated through 4 and provided in its upper portion with a diaphragm having a central hole 5. An anode 6, fed through 6a, consists of a copper tube open at both ends which, as illustrated, has a diameter of 50 mm, and an height of 500 mm. A coil 7 coaxial with the anode tube 6 creates in said tube a magnetic field of 200–500 gauss. A target 8, made of the material to be sputtered, is suspended by means 8o over the anode tube 6, lying parallel and relatively close to the anode tube axis. Oil circulated through 9 acts to cool the target when the target forming material cannot withstand the temperatures which may be attained by said target. The plate 10 to be coated is disposed on a support 11 of stainless steel which is directly connected to earth at 11a. An inlet valve 12 serves to admit an inert gas such as argon, which flows into vessel 11 through duct 12a. A vacuum unit, not shown, is connected to the vacuum vessel through a tube 13.

In this device, electrons are emitted by filament 2 which is heated to a temperature of 2,500° C. Said electrons are directed by tube 3 to the anode 6, which is at a positive potential ranging from 50 to 100 volts. The magnetic field of coil 7,
which ranges from 100 to 500 gauss and is parallel to the axis of anode 6, repels the electrons towards the anode axis by causing them to whirl around said axis. Argon coming in through valve 12 at a pressure from $10^{12}$ to $10^{14}$ torr is forced through the anode tube 6 and is ionized by the electrons from tube 3. Since the electrons are confined within the anode, the amount of argon molecules being ionized per unit volume is considerably increased. A 25 percent ionization ratio may be reached.

The anode current is of the order of 9 a. The ion current is of the order of 300-500 ma. across a target of 25 cm.$^2$ area, i.e. a current density of 12-20 ma./cm.$^2$. The ion flow is attracted by the target, which is at a negative potential of 800 volts. When the material to be sputtered is insulating, the voltage used on the target is caused to be alternatively positive and negative at a frequency from 13 to 20 MHz., so that the target under sputtering by the ion bombardment be neutralized by the electron bombardment.

Since the ion flow is concentrated near the anode tube axis, the target is arranged close and parallel to said axis so as to be at the highest ion density location. Usually, the part to be coated or workpiece is spaced from the target by less than 5 cm., so that the average free travel of the gas molecules is higher than said spacing and that the sputtered particles are not driven outside the space between the target and the workpiece.

With this arrangement, the rate of deposition can be five to 10 times higher than that obtained with the usual arrangements.

FIG. 2 shows an embodiment of the same device affording better handling facilities.

The vacuum vessel is formed of two compartments 14, 15 which can be connected through a coupling. Compartment 14, which is cooled through a coil 17, contains the filament fed by wires 18a, 18b and a tubular electrode forming the anode 19, which is fed at 19a. A diaphragm 22, with an axial aperture 22a, is arranged in front of filament 18. A magnetic coil 20 or a tubular magnet is coaxial with the anode tube 19.

A valve 21 serves to admit an inert gas or any other gas through duct 21a. Compartment 15 is closed at its upper portion by a removable cover 15a. Within compartment 15 are a target 23 fed at 23a and cooled by oil or air circulated through 24 and a support 25 for the object 26 to be coated. A vacuum unit not shown is connected to compartment 15 by a tube 27.

The values of the various parameters, viz., filament temperature, anode voltage, anode current, ion current density, target voltage, magnetic field, are of the same order as in the case of the device in FIG. 1.

It should be noted that, for the two devices illustrated, these parameters can vary within the following ranges:

<table>
<thead>
<tr>
<th>Filament Temperature</th>
<th>2000-2800°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode Voltage</td>
<td>50-200 volts</td>
</tr>
<tr>
<td>Anode Current</td>
<td>1-10 amp</td>
</tr>
<tr>
<td>Ion Current Density</td>
<td>up to 20 ma./cm.$^2$</td>
</tr>
<tr>
<td>Target Voltage</td>
<td>~400 to ~500 volts</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>up to 500 gauss</td>
</tr>
</tbody>
</table>

The device in FIG. 2 permits to increase the travel of the neutral plasma flow emerging from the anode tube and to coat objects of reasonable size. For this purpose, compartments 14, 15 are made separable so as to be more easy to construct. Compartment 14 has a length substantially equal to the length of the plasma flow travel. Compartment 15a is of sufficient capacity to accommodate objects of relatively great extent lying on support 25.

This device provides the following advantages:

1. Sputtering apparatus for depositing thin layers on substrates by ion-bombarding a target and sputtering material from the target to a substrate comprising: a vacuum chamber, evacuating means connected to the chamber for reducing pressure therein, an electron beam source mounted in the chamber comprising a filament, a diaphragm substantially covering the filament and having a central opening through which an electron beam projects, an elongated hollow cylindrical anode on an opposite side of the diaphragm from the filament and encircling the electron beam and extending substantially along an axis of the electron beam as it emerges through the diaphragm opening, ion beam generating means including said cylindrical anode and an electromagnetic coil surrounding said cylindrical anode, and gas injection means connected to the vessel and positioned therein for flowing gas into the cylindrical anode, first power supply means connected to the cylindrical anode for positively biasing the cylindrical anode and second power supply means connected to the coil for energizing the coil, whereby the cylindrical anode pulls electrons through the opening in the diaphragm whereupon plasma having positively charged ions is formed, whereby the cylindrical anode radially focuses positive ions, forming along its axis an ion beam, and whereby the magnetic coil propels the ion beam along the axis away from the diaphragm opening, a target mounted in the vessel on one side of the ion beam on an opposite end of the cylindrical anode from the diaphragm, a third power source connected to the target for negatively biasing the target and attracting ions to a surface thereof containing material to be sputtered, and a substrate mounted in the vessel adjacent the ion beam and having a surface to be coated positioned opposite the target for receiving material sputtered from the target.

2. The apparatus of claim 1 wherein filament comprises a helical wire having an axis and wherein axes of the filament, diaphragm opening, cylindrical anode and electromagnetic coil are concurrent.

3. The apparatus of claim 1 wherein the vacuum vessel comprises a main chamber and a tube opening into the main chamber and extending outward from an open connection therewith, wherein the filament, diaphragm and cylindrical anode are positioned within the tube and wherein the diaphragm opening, cylindrical anode have axes concurrent with a center of the open connection.

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