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A NEGATIVELY BIASED SUBSTRATE
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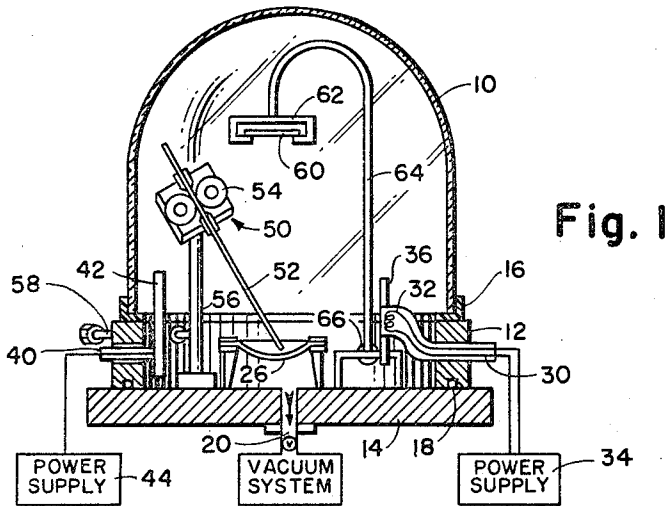


Fig. 1

Fig. 2

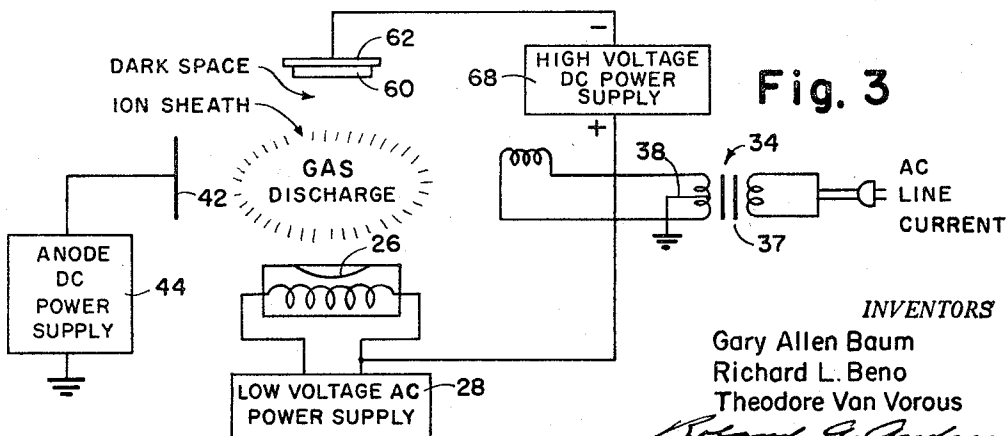
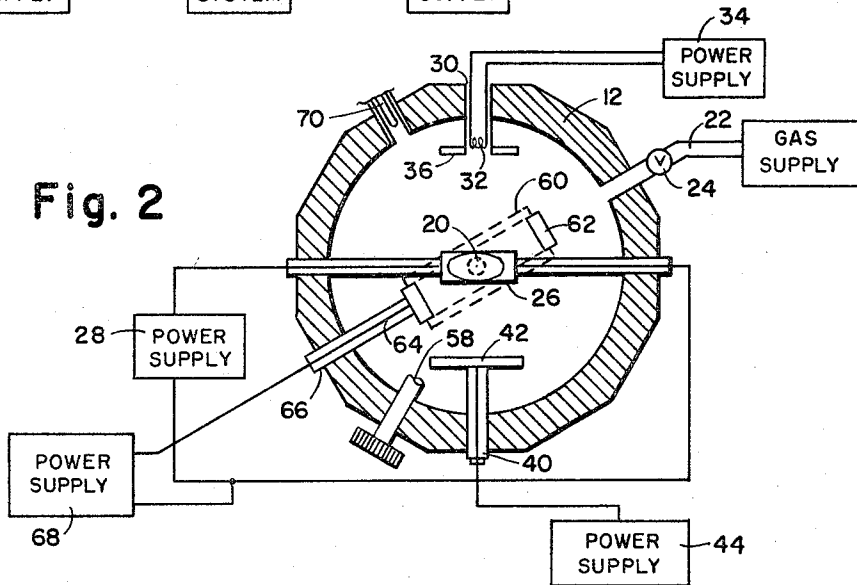


Fig. 3

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APPARATUS FOR VACUUM DEPOSITION ON A NEGATIVELY BIASED SUBSTRATE

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5 Claims

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This invention relates to the deposition of films on substrates and more particularly to the deposition of metallic ions, accelerated at low energy, on a substrate.

Many systems have been proposed for depositing thin metallic films on substrates. Basically the systems may be divided into two general techniques, vapor or thermal deposition and ionic deposition. In the first category, the depositant is simply heated until it vaporizes in the presence of the material to be coated and the vapor then condenses on the material, forming a film. A vapor deposited film is characterized by poor adherence, poor abrasion resistance, and is generally considered to be a rather poor quality film. However, it is an acceptable film for many purposes.

In the second category, a vaporized depositant may be ionized and then directed randomly or by magnetic fields or by a negative bias toward a substrate. A gas or glow discharge may be used to help ionize the depositant. Adherence of films deposited in this manner is generally better than that of ordinary vapor deposition or thermal processes. There are, however, several undesirable characteristics of ion deposition techniques. The gas or glow discharge requires a high potential, which has inherent problems associated therewith, such as insulation and shielding. The use of magnetic fields to direct the ions requires a prolixity of equipment which is both cumbersome and expensive. Moreover, high sputtering rates and the heating of the substrate are other problems attendant with these various techniques.

The present method is related generally to ion deposition techniques but is free from the problems attendant therewith while producing superior results. A filament is used to provide electrons for ionizing an inert gas and for ionizing a depositant. An anode is used to attract or direct the electrons given off by the filament in such a manner as to most efficiently utilize the electrons for the ionization of the gas and depositant. The apparatus described herein may be employed in the practice of the method. It comprises a tetrode device capable of accelerating depositant ions at low energy toward a substrate. Low voltages are employed by the method and apparatus as compared with other ionic deposition and glow discharge techniques. The separate electron source provides the electrons necessary to ionize the gas and the depositant without high voltage and the undesirable effects attendant thereto.

It is an object of this invention to provide a novel apparatus and method for coating a substrate.

It is another object of this invention to provide a novel apparatus and method for the ionic deposition of a metal on a substrate.

It is another object of this invention to provide a novel tetrode low energy accelerated ion deposition apparatus and technique.

This specification, including the description, drawing, and claims, has been prepared in accordance with the applicable patent laws and the rules promulgated under the authority thereof.

FIG. 1 is a sectional view of an embodiment of the described apparatus;

FIG. 2 is a view taken generally on line 2—2 of FIG. 1; and

FIG. 3 is a semischematic illustrative diagram of the circuit used herein.

In FIG. 1 is shown a bell jar 10 in sealed relationship to a metal collar 12 which in turn may be in sealed relationship to baseplate 14. The collar 12 may be of any suitable design and should preferably include a number of ports or pass-throughs to provide means for communicating with the interior of the apparatus. An elastomeric boot 16 may be used to effect a seal between bell jar 10 and collar 12. An O-ring 18 may be disposed in a groove in the collar to facilitate sealing the collar and the baseplate against leakage upon evacuating the jar. The bell jar, collar, and baseplate comprise a chamber in which the ion deposition process may be carried out. The baseplate may have extending therethrough a valved vacuum line 20 for evacuating the apparatus. A valved line 22 (FIG. 2) which may be connected to a source of inert ionizable gas, such as argon, may extend through a port or pass-through in collar 12.

Situated on the baseplate 14 may be crucible means 26, connected to a power supply 28 (FIG. 2). The electrical connection means for the evaporant source or crucible means may extend from power supply 28 to the evaporant source 26 through oppositely disposed ports in the collar, as shown in FIG. 2. The evaporant source may comprise a crucible of an appropriate refractory metal, such as tungsten, tantalum, titanium, molybdenum, or columbium (niobium), or it may be composed of nonconductive refractory material, such as a carbide, oxide, nitride, boride, or silicide as a hot pressed crucible. If the crucible is composed of a conductive material, it may itself be resistively heated, thus acting as its own heating element or filament. Nonconductive crucibles may be enclosed in a refractory metal cup for heating purposes. A particular crucible may be specifically chosen, according to the depositant to be used, such that its material will not react with the desired depositant. For example, a titanium diboride crucible may be selected when aluminum is to be used as the depositant because the two will not react together. If a filament heater or cup is used in conjunction with a nonconductive crucible, it should preferably be of a refractory metal and may heat the crucible by electron bombardment from the underside. The crucible may be supported by pins, if desired, which may also be fabricated of an appropriate refractory metal and which may be selectively paired with an appropriate crucible. For example, a titanium diboride crucible may be supported on tantalum pins. Another type evaporant source may comprise a conductive filament, such as tungsten, which may be resistively heated. Depositant material in a ribbon-like configuration may be placed on a conductive filament, which may be in the form of a coil, and may be evaporated by the resistive heating of the filament.

If it is desired to controllably feed depositant to the crucible or to control the amount of depositant, as opposed to placing a fixed, predetermined amount in the crucible, or on the filament a depositant feed mechanism 50 may be provided. Depositant wire 52 may be fed to crucible 26 or may be retracted from the crucible by contra-rotating feed pinions 54. The pinions may be rotated by conventional mechanical linkages such as by a gearing system operatively connected to a rotatable shaft in support member 56 which in turn may be operatively coupled to another rotatable shaft 58 which may extend through a port in collar 12. Thus rotation of shaft 58, through the intermediary of mechanical linkage, may effect controlled movement of the depositant wire and an

operator may accordingly control the amount of depositant vaporized and the speed at which the deposition process operates.

Extending through collar 12 may be electrical connection means 30 for supplying alternating current to thermionic filament 32, which may serve as a source of electrons, and electrical connection means 40 for supplying direct current to anode 42 which serves to attract electrons emitted by the filament. On the other end of connections 30 and 40 may be filament power supply 34 and anode power supply 44, respectively. Filament shield 36 may be press-fitted into a port in the collar and may serve as an electron reflector to increase the efficiency of the filament and anode. The filament and anode should preferably be operatively disposed intermediate the crucible 26 and substrate 60.

A substrate 60 may be supportably superposed over crucible means 26 by a substrate holder 62 and support means 64. The support means and holder should preferably include conductive material to provide an electrical path between electrical connection means 66 and the substrate for biasing the substrate negatively. Provisions may be incorporated with holder 62 for supporting a conductive screen (not shown) upon which the negative bias may be placed if the substrate to be coated is nonconductive. Under such circumstances the screen should preferably be supported from the holder beneath the substrate.

In FIGURE 2 the collar 12 is shown as having a circular interior and a twelve sided exterior with a plurality of ports or pass-throughs extending radially there-through. It may be noted that for illustrative clarity some liberties have been taken in both FIGURES 1 and 2. For example, the base support means 56 for the evaporant feed means 50 has been omitted from FIG. 2, and shaft 58 has been broken after extending through the collar. In FIG. 1 however, shaft 58 and its knob has been exaggeratedly extended. Other clarifying changes, omissions, etc., have also been made.

A conventional ion gage 70 for measuring the pressure within the apparatus may be positioned within a port in the collar 12. The information from the ion gage may be used in connection with the inert gas supply and valve 24. The valve 24 in gas line 22 may comprise a micrometer leak valve for providing a desired quantity of inert gas, such as argon, to the apparatus. Thus, when the vacuum pump has evacuated the apparatus to the desired pressure as measured by the ion gage, the leak valve 24 may be actuated and the desired amount of argon, as determined by pressure, may be bled into the apparatus.

An implosion shield (not shown), such as a protective screen, may be placed around the bell jar during operation of the apparatus. Conventional details, such as means for sealing the ports in the collar, and means for electrically insulating the various components and their circuits from each other, the collar, and the baseplate, have been omitted.

FIG. 3 discloses a semischematic diagram of the electrical circuits employed herein. The power supply 28 for the crucible or evaporant source 26 may be comprised of low voltage alternating current, supplying between 2,500 watts and 3,500 watts at from 50 to 10 volts and 50 to 350 amps. The high voltage may be matched with the low amperage and vice versa, and the two may be scaled together according to parameters determined by the substrate, depositant, and other considerations.

The filament power supply 34 may also comprise an alternating current, relatively low voltage and low amperage system. Regular A-C line voltage may be stepped down by transformer 37, the secondary of which may be center tapped to ground as at 38. Typical power requirements for the filament may be about 20 volts and 30 amps.

The anode power supply 44 may comprise a direct

current source of about 80 volts and 8 amps, which may be considered as a low voltage D-C power supply system.

A high voltage D-C power supply 68 may provide a negative bias for the substrate 60. During the actual deposition process, it may be desired to have a high voltage capability in order to initiate a gas or glow discharge. While a negative bias of only about 300 volts may be placed on the substrate to attract and accelerate the ionized depositant, it may be advantageous to have the capability of increasing the voltage to about 5,000 volts to initiate a gas or glow discharge. The negative bias may be placed on the substrate through the substrate holder 62, while the positive lead from supply 68 may be grounded to the heater or depositant power supply line, thus placing the potential difference between the evaporant supply and the substrate.

In operation, a vacuum pump may be used to evacuate the bell jar or chamber 10. At a pressure of about 10^{-4} torr the crucible heater power supply 28 and the filament power supply 34 may be turned on for cleaning and for preheating to prevent cracking. When outgassing from the two filaments has ceased, and a pressure of about 10^{-6} torr has been reached, the valve in line 20 may be partially closed and the valve 24 in line 22 may be opened slightly to backfill the apparatus with an inert ionizable gas such as argon. The valves may be adjusted until the chamber pressure stabilizes between 10^{-3} torr and 5×10^{-3} torr.

A positive potential may then be placed on the anode 42 and the filament 32 may be adjusted to its operating range. When both filament and anode are within their predetermined voltage parameters, which may depend on the pressure within the chamber, the depositant, and the substrate, the apparatus may then sustain a discharge if one can be initiated.

A discharge may be initiated in several ways. A high potential probe, such as a Tesla coil, if introduced into the chamber could be used to establish a discharge. Increasing the pressure of the argon gas until a breakdown of the gas occurs may also initiate a discharge. Under the circumstances, however, the simplest technique may simply be to establish a glow discharge between the evaporant source 26 and the substrate 60 by increasing the voltage or potential difference to at least about 1,000 volts or more. The glow discharge breaks down the gas and once this has occurred the filament and anode may maintain the discharge, thus allowing the voltage between the substrate and the evaporant source to be reduced.

The electrons emitted from the filament may be accelerated to the anode by the positive bias placed thereon. These electrons may ionize some of the argon atoms and thus produce more free electrons within the apparatus. The positive ions created may tend to randomly bombard the surface within the chamber, thus cleaning them. Thus sputtering or cleaning action on the substrate may be enhanced by placing a negative bias of about 200 volts thereon. This negative bias tends to accelerate the ions into the substrate. Increasing the kinetic energy of the ions by accelerating them therefore results in a faster sputtering and cleaning rate. This cleaning action may be carried out for any desired length of time.

Upon completion of the cleaning process the accelerated ion deposition may begin. The evaporant source or crucible 26 may be resistively heated to that temperature required to evaporate the depositant. By manipulating feed means 50 the amount of travel of depositant wire or rod 52 into and away from the crucible 26 may be controlled, thus determining the amount of depositant evaporated and indirectly controlling the rate and depth of deposition. Or, if desired, a measured or predetermined amount of depositant may be initially placed in the evaporant source or crucible means 26.

The actual accelerated ion film deposition may be started by placing a negative bias on the substrate 60.

This negative potential may vary up to about 400 volts, and may preferably be about 300 volts, depending on various conditions and circumstances, such as the substrate, the depositant, the pressure in the chamber, etc. Some of the vaporized depositant, or depositant vapor, in passing through the gas discharge, is ionized by collisions with free electrons, and, upon coming within the effects of the bias, is accelerated to the substrate.

Because the substrate 60 is placed in a gas discharge (FIG. 3) and is given a negative bias, a positive ion sheath forms around it. The entire bias voltage is then dropped between the substrate and the edge of this sheath. The area between the substrate and the edge of the sheath is known as the Langmuir dark space. An ion (whether a gas or a depositant ion) diffusing through the gas discharge is not affected by the bias until it arrives at the edge of the ion sheath. It will then be accelerated across the dark space and will arrive at the substrate with an energy equal to or less than the bias potential, depending on whether or not it underwent a collision in the dark space. Since the bias potential is low compared to the voltage usually required to sustain a gas discharge, the ions are accelerated at what may be termed low energy.

It appears that not all of the vaporized depositant may be ionized and accelerated into the substrate. Various experiments seem to indicate that some of the material may never become ionized and that some of the ionized material may recombine with an electron before reaching the ion sheath. Thus the resulting film on the substrate is formed by both accelerated ions and thermal atoms.

Various adhesion and abrasion tests have indicated that the film resulting from this method and apparatus is superior to that of other techniques presently employed. The use of such a tetrode device, having a separate filament for providing electrons and a separate anode for attracting the electrons through an ionizable gas and a vaporized depositant appears to offer several advantages. The filament may provide a far greater number of electrons available for ionizing the gas atoms in the gas discharge and for ionizing the vaporized depositant than conventional ion deposition devices. Moreover, with the device and technique herein described it is possible to use a wide variety of metals as depositant, including metals which have been heretofore characterized as difficult to ionize and to coat on a substrate.

The heating of the substrate results from the bombarding ions, whether during the cleaning process or during the actual deposition process. An ion that is accelerated through a potential difference acquires the potential energy equal to the ionization charge times the voltage. If this ion were to collide with the substrate without knocking off a substrate atom, then the acquired energy of the ion is transferred to the substrate in the form of heat energy. Thus the greatest temperature rise may occur during the cleaning process because the cleaning process takes longer than the deposition process. However, it may be readily understood that heating of the substrate is minimized with the present process because of the use of low voltage as compared with other techniques. This is so even though the present invention pro-

vides a greater electron density, by providing a separate filament supply, and thus a greater degree of gas ionization than prior art devices.

The use of four electrodes, including a filament which acts as an emitter or source of electrons, provides for a greater probability of ionizing both an inert gas and a vaporized depositant, which in turn results in superior cleaning of the substrate and in superior ionic deposition thereafter. The film which results from this technique appears to have superior adhesion and abrasion characteristics. The low voltages used eliminate costly equipment, shielding, and other problems attendant with high voltages, but still impart to the ions sufficient energy to form a tough, durable film.

We claim:

1. Apparatus for depositing low energy accelerated ions on a substrate comprising, in combination, a chamber, means for controllably evacuating the chamber, means for controllably admitting an inert ionizable gas into the chamber, means for supporting and positioning a substrate within said chamber, an evaporant source for supporting evaporant material within the chamber spaced from the substrate, means associated with the evaporant source for heating the source and the evaporant material, thermionic filament means for providing a source of electrons for ionizing the inert gas and the evaporant, anode means spaced from the filament means for attracting electrons emitted by the filament, said filament means and said anode means being operatively disposed intermediate the substrate and the evaporant source, and means for biasing the substrate negative with respect to the evaporant source to attract and accelerate ionized evaporant material to said substrate for deposition thereon.

2. The apparatus of claim 1 in which the filament means includes a filament power supply for resistively heating the filament to provide electrons and the anode means includes an anode power supply for biasing the anode positive with respect to the filament for attracting the electrons.

3. The apparatus of claim 1 in which the evaporant source includes a refractory metal crucible.

4. The apparatus of claim 1 in which the evaporant source includes a nonconductive crucible.

5. The apparatus of claim 1 in which the evaporant source includes a conductive filament.

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