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[73] Assignee **The United States of America as represented by the United States Atomic Energy Commission**

[54] **ION BEAM DEPOSITION SYSTEM**
8 Claims, 2 Drawing Figs.

[52] **U.S. Cl.** **118/49.5,** 219/121EB
[51] **Int. Cl.** **C23c 13/12**
[50] **Field of Search** ..... 118/6, 7, 8, 49.1, 49.5; 219/121 EB; 117/Inquired, 93.4, 93.44, 200—233

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ABSTRACT: An ion-beam deposition system including means for providing atoms of depositant material to an ionization region, first and second means for injecting electrons into the ionization region to ionize said depositant atoms, means for periodically and individually energizing the first and second injecting means, and means for extracting and accelerating ions from the ionization region to a substrate.

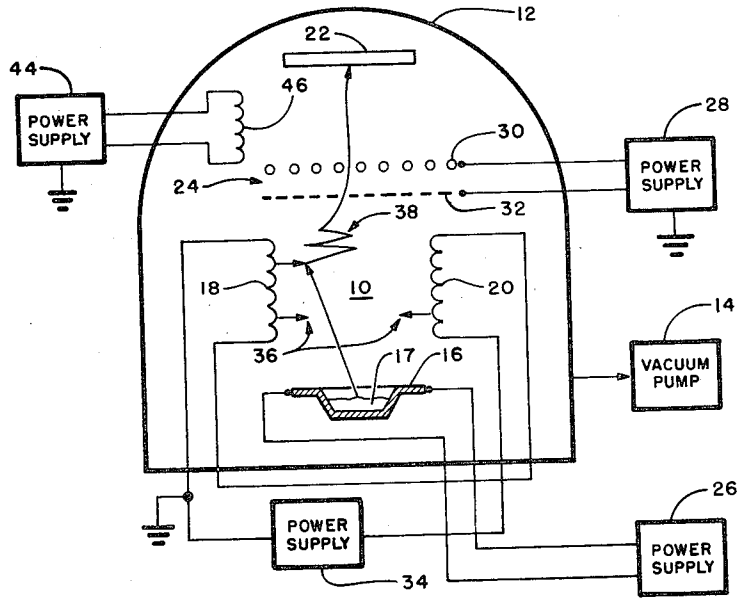


FIG. 1

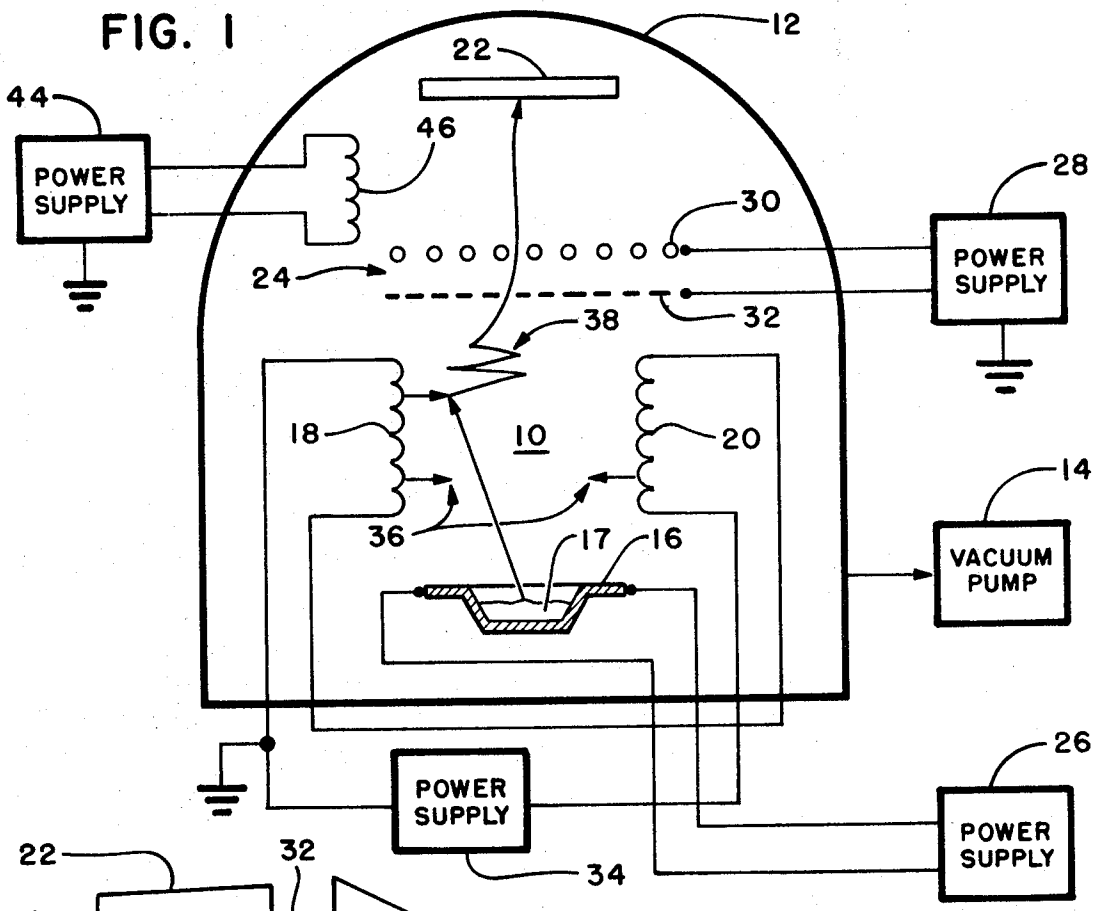
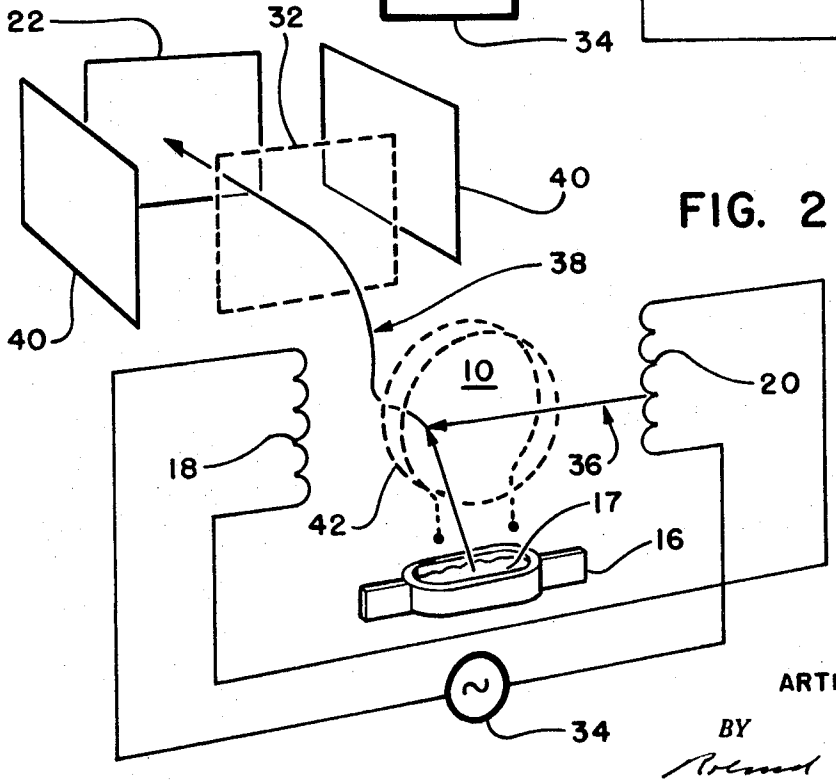


FIG. 2



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ION BEAM DEPOSITION SYSTEM

BACKGROUND OF INVENTION

Films or layers of material may be deposited on substrates by various techniques, for example, vapor deposition, various types of sputtering, and ion-beam deposition. Each of these techniques and other related techniques may have certain advantages for particular applications and in some cases may be combined to provide some desired combination of advantages to achieve a particular finished product.

Ion-beam deposition techniques generally provide the advantage of obtaining good film adhesion by ion bombardment cleaning of the substrate surface and ion penetration of substrate surface. However, previous ion-beam deposition techniques and systems may be limited as to the ion current output (e.g., deposition rate) to the substrate, and therefore limited as to deposition rates, due to, among other things, inherent ion losses within the system from attraction by negatively biased electrodes required by the system. If an attempt is made to control ion losses to biased electrodes, very high extraction and acceleration voltages are used to draw the ions from the ionization region before they are attracted to these electrodes. Such high voltage acceleration and extraction voltages increase the difficulties in controlling the ion beam and the energies of the ions striking the substrate. For example, as the acceleration voltage is increased, a greater portion of the ions striking the substrate will serve to sputter off part of the substrate rather than contribute to the deposition. It has been found in many cases, that the extraction voltage gradient must be so high to achieve ion extraction from the ionization region, therefore, the extraction region itself must be small, and deposition rates are at a low level.

Ion deposition systems which require high extraction and acceleration voltages to overcome space charge and other electric fields within the ionization region may accelerate ions against the substrate with a wide range of energies. Such variations and nonuniformities in ion energies do not permit control of deposited film properties. Further, ions striking the substrate cause the substrate to be heated. If a sufficient number of these ions are of high energy, the substrate may be heated to a degree which may also adversely affect the deposited film. Thus, it may be necessary to cool the substrate, decrease the rate of deposition or decrease the extraction and acceleration voltages. Maintaining high electric fields in the presence of metal ions is very difficult because of the insulation system which is required.

Many prior ion deposition system also require some type of carrier gas to achieve ionization of the depositant material. Since the carrier gas is also ionized, these gas ions may be accelerated to the substrate and form a part of the deposited film. In many applications, such gas deposition may be detrimental to the final product.

SUMMARY OF INVENTION

In view of the limitations of the prior art as noted above, it is an object of this invention to provide an ion-beam deposition system capable of high ion current output and high efficiency with low extraction and acceleration voltages.

It is a further object of this invention to provide an ion-beam deposition which is capable of producing high ion currents and uniform ion energies with a low extraction voltage.

It is a still further object of this invention to provide an ion-beam deposition system with high ion current output without a carrier gas under a vacuum.

Various other objects and advantages will appear from the following description of embodiments of the invention, and the most novel features will be particularly pointed out hereinafter in connection with the appended claims. It will be understood that various changes in the details, materials and arrangements of the parts, which will herein be described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principles and scope of the invention.

The invention comprises an ion-beam deposition system in which ions are produced for acceleration to and deposition on a substrate by at least two electron sources periodically injecting electrons into an ionization region against atoms of depositant material.

DESCRIPTION OF DRAWINGS

The present invention is illustrated in the accompanying drawing wherein:

FIG. **1** is a diagrammatic view of an ion beam deposition system incorporating this invention; and

FIG. **2** is a diagrammatic view in perspective of an alternate embodiment of this invention.

DETAILED DESCRIPTION

FIG. **1** illustrates diagrammatically an ion-beam deposition system which incorporates principles of this invention. It will be readily apparent, that the various elements and apparatus utilized in this system may be standard or conventional apparatus, such as conventional thermionic filaments, grids, accelerating electrodes, etc.

The ion-beam deposition system shown in FIG. **1** includes an ionization region **10** disposed within a suitable container or bell jar **12** which may be evacuated by a suitable vacuum pump **14** to some desired level of vacuum, such as from about 10^{14} to 10^{110} Torr. A source **16** of depositant material **17** may be disposed within bell jar **12** adjacent to the ionization region **10** to provide atoms of the depositant material to region **10**. At least a first electron source **18** and a second electron source **20** may be disposed at different and spaced-apart positions, such as at opposite locations, about ionization region **10** to supply electrons to region **10** and ionize atoms of the depositant material. Additional electron sources or electron source pairs may be positioned about ionization region **10** at different locations to provide increased electron injection into region **10** and further decrease ion attraction to electron sources. The ionized depositant material may then be withdrawn from ionization region **10** and accelerated to a suitable substrate **22** by extraction and acceleration means **24**.

Source **16** may be any conventional source which will evaporate or otherwise provide atoms to ionization region **10**. The source **16** is illustrated as a conventional evaporation source or boat heated by power supply **26**.

Substrate **22** may be of any convenient or desired shape, cross section or size and be made of either a nonconductive or conductive material. As a conductive material, substrate **22** may form a part of the accelerating means by biasing substrate **22** to an accelerating voltage. On occasions, substrate **22** may be a nonconductor so that the accelerating voltage may be applied by a power supply **28** to an appropriately designed grid **30** which will permit the accelerated ions to pass therethrough to substrate **22**. For insulating substrates, the ions tend to build up a charge which would prevent additional deposition. To permit use of insulating substrates an electron emitter **46** can be added in the region of the substrate and be powered by power supply **44**. The electrons are repelled by the extraction grid and attracted by any charge buildup on the substrate. The extraction field may be achieved by a separate grid **32** disposed adjacent ionization region **10** and energized by power supply **28** to an extraction voltage. Grid **32** preferably is designed, like grid **30**, so as not to obstruct passage of ions through the grid.

Electron sources **18** and **20**, and any other sources used, may be energized by power supply **34** so that each individual electron source emits electrons at separate and alternating periods of time. For example, electron sources **18** and **20** may be thermionic emitters connected in series with power supply **34** which provides an alternating current to the electron sources. With such an arrangement the electron sources will alternately emit electrons into the ionization region **10** and extract electrons therefrom, alternately acting as a cathode and an anode. It will be clear, that power supply **34** may be any ap-

propriately controlled pulse, square wave or the like source which periodically energizes the electron sources. The frequency of energization should be selected so that electrons emitted by a source have sufficient time to traverse a major or sufficient portion of the ionization region to ensure collision with an atom of depositant material without permitting any of the depositant ions to be attracted to the energized electron source. Thus, when the electrons travel into ionization region **10**, as shown by arrows **36**, and ionize an atom of depositant material, the depositant ion may have a path such as shown by line **38** which is generally sinusoidal in shape as the extraction voltage pulls the ion from region **10**. It has been found that the frequency of electron source energization may be varied from about 40 Hz. to about 10,000 Hz. With a frequency greater than 10,000 Hz., the electrons may not traverse a sufficient portion of region **10** whereas at less than 40 Hz., the ions may reach an electron source before the bias changes. With such arrangement and a source energization frequency of about 60 Hz., for copper depositions, the extraction voltage may vary from about a −30 to −130 volts DC with an acceleration voltage of between about −25 to about −200 volts DC. Other depositant materials will require approximately the same extraction and acceleration voltages. With greater acceleration voltages, such as for copper of about −250 volts or more, a greater amount of substrate will be sputtered off than depositant material deposited so as to provide a cleaning of the substrate. The depositant can be all or partly a gas. For example, aluminum can be evaporated while the appropriate partial pressure of oxygen is being maintained and aluminum oxide be formed at the substrate. Likewise, an aluminum film can be deposited, then bombarded with oxygen to build an electrode covered with aluminum oxide insulation.

The ion-beam deposition system of FIG. **1** may be operated by evacuating, at least partially, bell jar **12** and then heating or otherwise energizing the depositant material source **16** to supply depositant material atoms to ionization region **10**. If the absolute pressure in the bell jar is above 10^{14} torr, there will be significant amounts of residual as well as that which may be intentionally introduced ambient gas entering the ionization region and being deposited as impurities. Electron sources **18** and **20** may thereafter be energized by power supply **34** in the appropriate manner described above to alternately inject electrons into ionization region **10** and ionize the atoms of depositant material. In this FIGURE, it may be noted that the current from power supply **34** provides heating for electron sources **18** and **20** as well as electron acceleration voltage. These two functions may be provided by separate power supplies. These ions may then be extracted or withdrawn from ionization region **10** by grid **32** and accelerated against substrate **22** by grid **30**. Since the extraction voltage does not have to pull the ions away from and overcome the electric field produced by the energized electron sources which are varying in polarity, the extraction and acceleration voltages may be kept at a low level. It will be clear that an initial acceleration voltage may be selected which may accelerate depositant ions with sufficient energy to clean substrate **22**. The acceleration voltage may then be decreased to form the desired deposit.

This configuration, having at least two electron sources which are reversed periodically, may neutralize the field produced by the ions and prevent the electron sources from extracting ions to provide a relatively low net charge in the ionization region and prevent space charge limitations. The present system may produce ion beams of from about 10 to 500 milliamperes intensity to provide deposition rates from about 5 to 250 angstroms per second. Due to the cleanliness of the substrate as a result of ion beam cleaning and from the vacuum environment and ion deposition, this system provides well formed, and highly adhesive deposition films. The cleaning agent can be the same as the depositant thus assuring high purity. Further, the substrate temperature may be kept at a relatively low temperature without decreasing beam current.

It may be desirable in some applications to provide a greater percentage of ions to atoms in the depositing film. This may be accomplished, by utilizing some form of ion beam deflection as the ions are extracted from ionization region **10**. Such an ion-beam deflection may be achieved with a magnetic field applied parallel to the electric field between electron sources **18** and **20**, or by placing the extraction grid at an angle other then 90° with respect to the initial path of atoms from source **16**, as shown by the embodiment shown in FIG. **2**. The ion beam extracted from the ionization region **10**, may be collimated and focused by suitable biased collimating electrodes **40**.

The electrical leads for electron sources **18** and **20** may inherently generate certain stray magnetic fields which may effect some form of magnetic magnification of electron paths, enhancing ionization in the systems of FIG. **1** and FIG. **2**. It may be desirable in certain applications to increase this magnification to increase the percentage of ionization of the depositant material atoms. This may be accomplished by applying an alternating magnetic field perpendicular to the initial path of the depositant material atoms provided by source **16** and perpendicular to the electric field of the electron sources, as shown by the dotted lines **42** outlining a magnetic coil. The magnetic field, for greatest extraction efficiency, may have to alternate in phase with the electric field of the electron sources.

I claim:

1. A system for depositing ions on a substrate from an evacuated ionization region comprising means for providing deposition atoms to said ionization region, first and second means for injection electrons into said ionization region for ionizing said deposition atoms, means for periodically and individually energizing said first and second injecting means, and means for extracting ions from said ionization region and accelerating them to said substrate.

2. The system of claim **1**, wherein said first and second means are positioned at spaced-apart locations about said ionization region.

3. The system of claim **1**, wherein said first and second means are electron emissive cathodes.

4. The system of claim **1** wherein said deposition atom providing means is an evaporation source.

5. The system of claim **1**, including means for forming said ions into a beam.

6. The system of claim **1** wherein part or all of said deposition atom providing means is a gas.

7. The system of claim **1**, in combination with charge neutralization means at the substrate.

8. The system of claim **1** including means for producing a magnetic field for improving ionization efficiency by increasing electron path length.