June 2, 1970 G. E. BODWAY 3,515,663

TRIODE SPUTTERING APPARATUS USING AN ELECTRON EMITTER

Filed Feb. 1, 1968 3 Sheets-Sheet 1

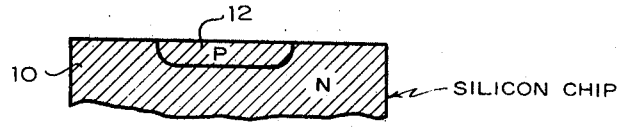

Figure 1

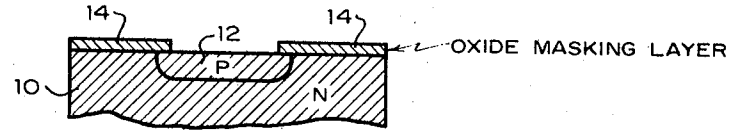

Figure 2

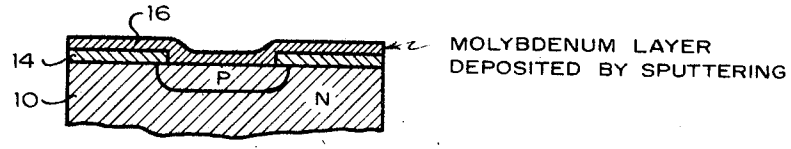

Figure 3

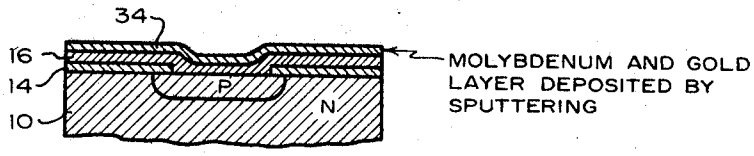

Figure 4

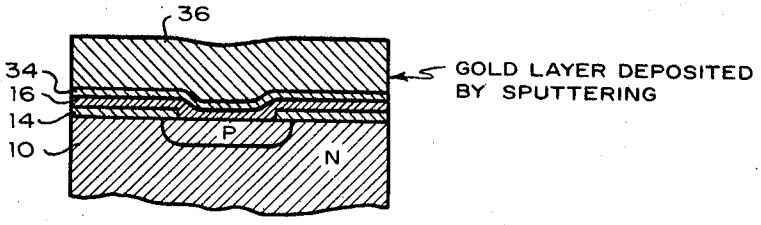

Figure 5

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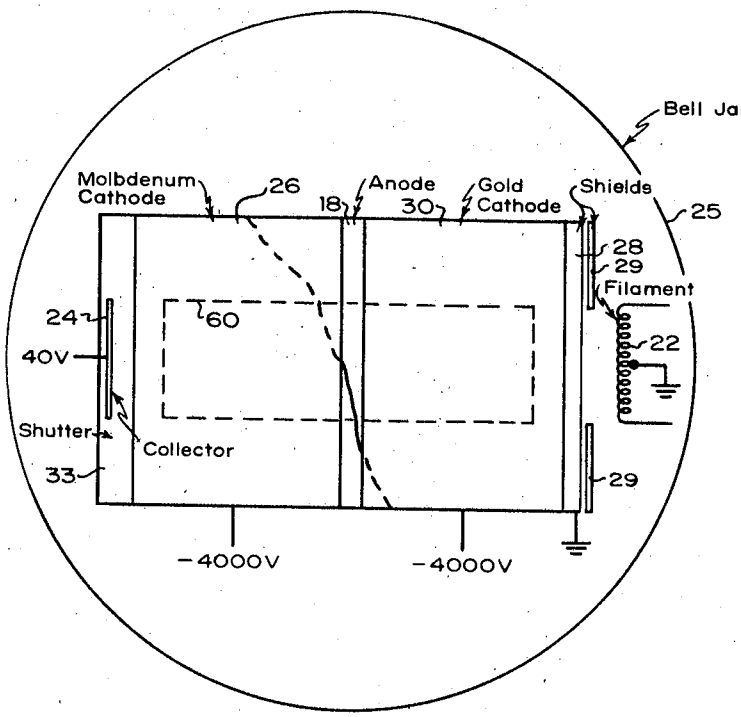
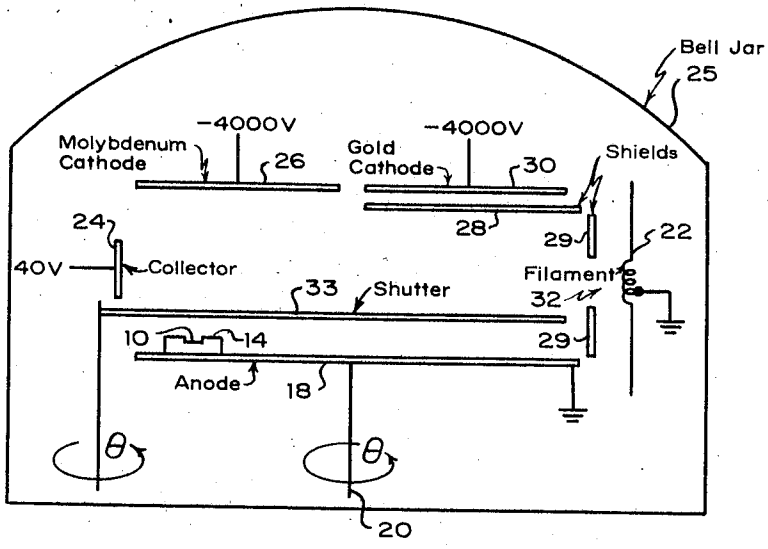
TRIODE SPUTTERING APPARATUS USING AN ELECTRON EMITTER

Filed Feb. 1, 1968 3 Sheets-Sheet 2



PRIOR ART

Figure 6



PRIOR ART

Figure 7

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TRIODE SPUTTERING APPARATUS USING AN ELECTRON EMITTER

Filed Feb. 1, 1968 3 Sheets-Sheet 3

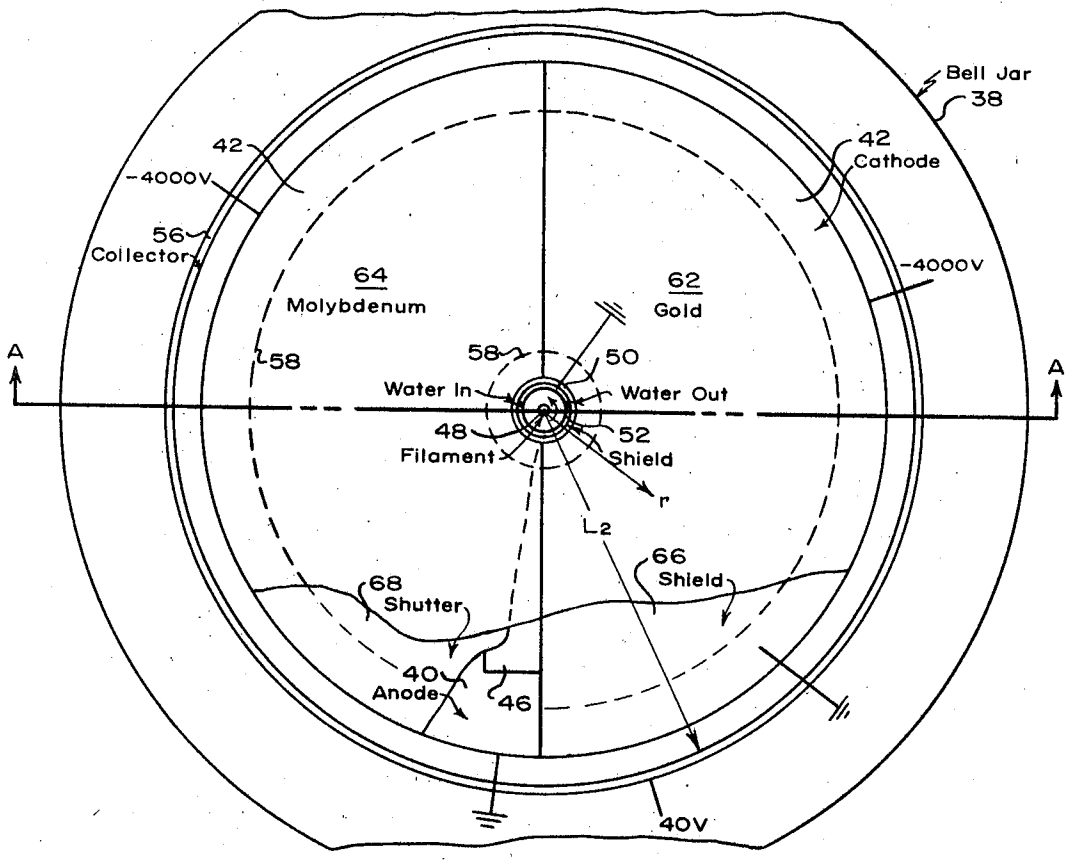

Figure 8

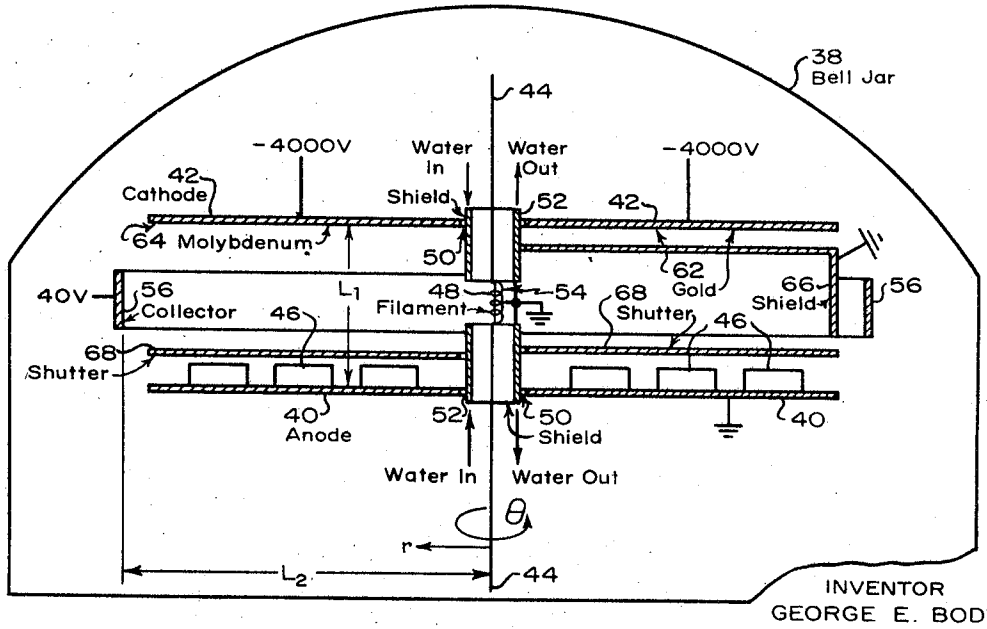

Figure 9

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TRIODE SPUTTERING APPARATUS USING AN ELECTRON EMITTER

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Int. Cl. C23c 15/00
U.S. Cl. 204—298 10 Claims

ABSTRACT OF THE DISCLOSURE

A triode sputtering system having a circular anode and a circular cathode spaced apart a distance approximately equal to the mean free path of the atoms to be sputtered from the cathode. A cylindrical collector is positioned between the anode and the cathode and around a shielded filament that is rotatably supported along a common axis of the anode and the cathode. The collector is symmetrically spaced from the filament a distance approximately equal to the mean free path of electrons. A semicircular shield is provided for use in shielding a selected portion of the cathode. The above-described structure is mounted within a bell jar filled with an inert gas at low pressure.

BACKGROUND AND SUMMARY OF THE INVENTION

This invention relates to a method of forming a stable and adherent metal contact on an element and to an improved triode sputtering system that may be used in performing the steps of this method.

A good metal contact should be malleable and easily bondable by either thermocompression or ultrasonic bonding. It should also have good electrical conductivity and should not oxidize. Gold contacts have these properties. However, gold is not adherent to most materials, has a high diffusion coefficient through most materials, and reacts with materials such as silicon to form a low temperature eutectic. These disadvantages of gold contacts can be overcome by using a nonreactive interface layer between the gold contact and the element on which the gold contact is to be formed. This interface layer may comprise, for example, molybdenum, nickel, chrome, or titanium. Molybdenum is preferred because gold has perhaps its lowest diffusion rate through molybdenum—about two or three orders of magnitude lower than through the other metals mentioned. Molybdenum will oxidize, but this presents no problem since the interface layer will be covered by the gold contact.

It is an object of this invention to provide a production oriented method of forming a stable and adherent metal contact on an element such as an active device, thin film circuit, beam lead structure, or the like. This object is accomplished according to the preferred embodiment of the method by sputtering a layer of molybdenum onto the element, by sputtering a mixed layer of gold and molybdenum onto the layer of molybdenum, and by sputtering a layer of gold onto the mixed layer of gold and molybdenum.

The sputtering steps of this method may be accomplished by employing a conventional triode sputtering system. However, in conventional triode sputtering systems, uniform deposition is limited to a relatively small area. This minimizes the usefulness of the method in large scale production set-ups where it is desirable to uniformly process large numbers of elements at the same time.

Accordingly, it is another object of this invention to provide an improved triode sputtering system in which uniform deposition may be accomplished over a comparatively large area at low gas pressures. This object is

accomplished according to the preferred embodiment of this system by employing an enlarged circular anode and an enlarged circular cathode mounted in parallel planes and spaced apart along a common axis by a distance approximately equal to the mean free path of the atom to be sputtered from the cathode. A shielded filament is rotatably mounted along the common axis and between the anode and the cathode, and a cylindrical collector is coaxially mounted around the shielded filament. The collector is positioned between the anode and the cathode and is symmetrically spaced from the filament by a distance approximately equal to the mean free path of electrons.

DESCRIPTION OF THE DRAWINGS

FIGS. 1 through 5 are sectional views illustrating the steps of forming a metal contact on an element according to the preferred embodiment of the method of this invention.

FIG. 6 is a partially cut away top view of a conventional triode sputtering system that may be used in performing the steps illustrated in FIGS. 1 through 5.

FIG. 7 is a side view of the conventional triode sputtering system of FIG. 6.

FIG. 8 is a partially cut away top view of an improved triode sputtering system according to the preferred embodiment of the system of this invention.

FIG. 9 is a sectional side view taken along the line A—A of the improved triode sputtering system of FIG. 8.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown an element such as a silicon chip **10** on which a metal contact is to be formed. The metal contact to be formed may serve, for example, as an electrode of a circuit element **12** previously formed in the silicon chip **10** by conventional diffusion techniques. As shown in FIG. 2, it may initially be necessary to provide an oxide masking layer **14** or the like on the surface of the silicon chip **10** to prevent the metal contact from contacting selected portions of the silicon chip **10**. Alternatively, a masking layer might be employed after the metal contact is formed on the silicon chip **10** to permit removal of selected portions of the metal contact by etching.

As shown in FIG. 3, the first step in forming the metal contact on the silicon chip **10** comprises sputtering a layer **16** of molybdenum or some other such adherent and nonreactive metal onto the exposed surface of the silicon chip. This step may be accomplished, for example, by employing a conventional triode sputtering system such as that shown in FIGS. 6 and 7. The silicon chip **10** is placed on a rectangular anode **18** that is operated at ground potential. Anode **18** is mounted so that it can be rotated in the θ direction about the axis **20**. Electrons from a filament **22** that is operated at ground potential are collected at a collector **24** that is operated at about forty volts. A current flow of about two amperes is maintained between the filament **22** and the collector **24**. The sputtering apparatus is housed in an enclosure **25** filled with an inert gas such as argon. Thus, some of the electrons from the filament **22** collide with neutral argon atoms before reaching the collector **24**. Some of these collisions produce positive argon ions, which are attracted to a rectangular molybdenum cathode **26** that is operated at about four thousand volts negative with respect to ground. As the positive argon ions bombard the molybdenum cathode **26**, molybdenum atoms are sputtered off. Many of these molybdenum atoms are deposited on the siilcon chip **10**. This process is continued for about two and a half to five minutes to sputter a layer **16** of molybdenum about five hundred to one thousand angstroms in thickness onto the exposed surface of the silicon chip **10**. A

rectangular shield **28** is employed to prevent the positive argon ions from bombarding a rectangular gold cathode **30** to be used in the next step. A filament shield **29** is provided with an opening **32** for permitting electrons from the filament **22** to reach the collector **24**. Prior to the first sputtering step, a rectangular shutter **33** may be positioned between the silicon chip **10** and the cathodes **26** and **30**. The shutter **33** shields the silicon chip **10** during a brief sputtering operation that is employed to clean the triode sputtering system. After this cleaning operation, the shutter **33** is rotated out of the sputtering region, and the first sputtering step is performed as described above.

As shown in FIG. 4, the next step in forming the contact comprises sputtering a mixed layer **34** of molybdenum and gold, or some other such metal that is malleable, bondable, electrically conductive, and oxidation resistant, onto the layer **16** of molybdenum. This step may also be accomplished by using the conventional sputtering system shown in FIGS. 6 and 7 and described in connection with the preceding step. However, for this step both the molybdenum and the gold cathodes **26** and **30** are operated at four thousand volts negative with respect to ground. In addition the anode **18** and the shield **28** are rotated together in the θ direction about the axis **20** at an angular speed of about one to ten revolutions per minute. Thus, positive argon ions alternately bombard the molybdenum and gold cathodes **26** and **30**. This process is continued for about two to three minutes to sputter a mixed layer **34** of gold and molybdenum about four to six hundred angstroms in thickness onto the layer **16** of molybdenum.

As shown in FIG. 5, the final step in forming the contact comprises sputtering a layer **36** of gold onto the mixed layer **34** of gold and molybdenum. This step may also be accomplished by using the conventional sputtering system shown in FIGS. 6 and 7. However, for this step the anode **18** and the shield **28** are held stationary, and the shield **28** is positioned to shield the molybdenum cathode **26**. Thus, the positive argon ions bombard only the gold cathode **30**. This process is continued for about twenty minutes to sputter a layer **36** of, for example, about four thousand angstroms in thickness onto the mixed layer **34** of gold and molybdenum.

The above three steps provide a metal contact that is substantially more stable and that is about ten times more adherent to a silicon chip or the like than, for example, a simple gold contact formed by conventional methods. Although these steps may be accomplished by employing the conventional triode sputtering system described above, they are better accomplished on a large scale production basis by employing the improved triode sputtering system described below.

Referring now to FIGS. 8 and 9, there is shown an air tight housing such as a bell jar **38**. The bell jar **38** is evacuated and then filled at a low pressure of about four microns with an inert gas such as argon. A circular anode **40** operated at about ground potential and a circular cathode **42** operated at about four thousand volts negative with respect to ground are mounted in parallel planes within the bell jar **38**. The anode **40** and the cathode **42** are spaced apart along a common axis **44** by a distance L_1 approximately equal to the mean free path 1_a of the atoms to be sputtered from the cathode. This distance L_1 may have virtually any value within the range of values defined by 1_a plus or minus one hundred percent. Specifically, a value of about one and six-tenths inches may be used. The anode **40** and the cathode **42** may each have a radius of about eight inches. This makes them about four times larger in area than the anode **18** and the combined cathodes **26** and **30** of the conventional triode sputtering system shown in FIGS. 6 and 7. The elements **46** on which a film is to be deposited are placed on the anode **40**. A cathode **42** is

employed that is made of the material to be deposited on the elements **46**.

A filament **48** operated at ground potential is rotatably mounted within the bell jar **38** along the common axis **44** between the anode **40** and the cathode **42**. The filament **48** is rotated at an angular speed in the θ direction of about one to ten revolutions per minute. This rotation of the filament **48** assures uniformity of deposition in the θ direction. The anode **40** and the cathode **42** are each provided with a central opening **50** for receiving the end terminals of the filament **48**. A cylindrical shield **52** is coaxially supported around the filament **48**. The shield **52** comprises two half sections that protrude through the openings **50** in the anode **40** and the cathode **42** and that are spaced apart near the center of the filament **48** to provide an annular opening **54** through which electrons may leave the filament. Each half section of the shield **52** has hollow walls through which water is pumped to provide cooling for the filament **48**. A cylindrical collector **56** is coaxially mounted within the bell jar **38** and around the shielded filament **48**. The collector **56** is mounted between the anode **40** and the cathode **42** and is symmetrically spaced from the filament **48** by a distance L_2. The gas pressure within the bell jar **38** is adjusted to make the mean free path 1_e of electrons approximately equal to L_2. The collector **56** is operated at about 40 volts.

Electrons given off by the filament **48** are collected by the collector **56**. A current flow of about four amperes is maintained between the filament **48** and the collector **56**. The electron density falls off naturally as the reciprocal of distance r from the filament due to geometry. Some of the electrons from the filament **48** collide with neutral argon atoms while in transit to the collector **56**. The probability that such a collision will occur increases with r from zero at the filament **48** to a maximum at the mean free electron path length near the collector **56**. Some of these collisions produce positive argon ions that bombard the negatively biased cathode **42** and thereby sputter atoms of the material to be deposited away from the cathode. The probability that an electron will ionize a neutral argon atom as a collision is made also increases with r. Thus, by balancing the increase in collisions and resultant ionizations with r against the decrease in electron density with r, a uniform ion density and, hence, a uniform deposition is obtained. This is accomplished by making L_2 approximately equal to the mean free electron path length 1_e. For good uniformity of deposition 1_e should be equal to at least fifty percent of L_2; 1_e may exceed L_2 by virtually any amount. Depositions of about plus or minus ten percent uniformity have been obtaied when 1_e has a value within the range of values defined by L_2 plus or minus ten percent. Such a deposition may be obtained with the above-described apparatus over an area (indicated between the concentric broken lines **58**) greater than one hundred square inches. This area is about ten times greater than the area (indicated within the rectangular broken line **60** in FIG. 6) over which a comparably uniform deposition can be obtained with the conventional triode sputtering system shown in FIGS. 6 and 7.

If, for example, metal contacts are to be formed on the elements **46** by the method described above, a cathode **42** is employed having one half section **62** made of gold and another half section **64** made of molybdenum. A semicircular shield **66** is employed to cover the gold half section **62** of the cathode **42** and the corresponding portion of the collector **56** during the step of sputtering a layer of molybdenum onto the elements **46**. The shield **66** is removed, and the anode **40** is rotated with the filament **48** during the next step of sputtering a mixed layer of gold and molybdenum. Rather than remove the shield **66** during this step it may also be rotated ninety degrees to a neutral position equally between the half

sections **62** and **64** of the cathode **42**. The shield **66** is then rotated an additional ninety degrees to cover the molybdenum half section **64** and the corresponding portion of the collector **56** during the next and last step of sputtering a layer of gold onto the mixed layer of gold and molybdenum. A pair of semicircular shutters **68** may be positioned between the elements **46** and the cathode **42** to shield the elements **46** during the cleaning operation that is performed prior to the first sputtering step. These shutters **68** are mounted so that they may be rotated to positions aligned with the neutral position of the shield **66** after the cleaning operation is finished.

I claim:

1. Apparatus for depositing a layer of a selected material on an element, said apparatus comprising:

an enclosure for maintaining an inert gas at a selected pressure;

an anode housed within said enclosure;

a cathode housed within said enclosure and spaced from said anode to define a discharge region;

a filament housed within said enclosure and positioned between said anode and said cathode to emit electrons along a path passing through said discharge region between said anode and said cathode; and

a collector housed within said enclosure and positioned between said anode and said cathode, said collector being positioned at least partially around said filament and being substantially radially spaced therefrom by a selected distance.

2. Apparatus as in claim **1** wherein said collector is spaced from said filament by a distance approximately equal to the mean free path of electrons.

3. Apparatus as in claim **2** including a shield housed within said enclosure and operable for cooling said filament, said shield being positioned around said filament and having an annular opening through which electrons may pass from the filament to the collector.

4. Apparatus as in claim **3** wherein:

said anode and said cathode are supported in parallel planes and along a common axis;

said filament is rotatably supported along said common axis and between said planes; and

said collector is coaxially supported around said filament and between said anode and said cathode.

5. Apparatus as in claim **4** wherein:

said cathode comprises the selected material; and

said anode and said cathode are spaced apart by a distance approximately equal to the mean free path of the atoms to be sputtered from the cathode.

6. Apparatus as in claim **5** wherein:

said anode and said filament are each to be operated at a reference potential;

said collector is to be operated at a selected positive potential relative to the reference potential of said anode; and

said cathode is to be operated at a selected negative potential relative to the reference potential of said anode;

whereby some of the electrons emitted from said filament collide with neutral atoms of said inert gas and produce positive ions that are attracted to said cathode where they sputter off atoms of the material to be deposited on said element.

7. Apparatus as in claim **6** wherein:

said anode and said cathodes are circular; and

said collector and said shield are cylindrical.

8. Apparatus as in claim **2** wherein: said anode and said cathode are supported in parallel planes and along a common axis; said filament is rotatably supported along said common axis and between said planes; and said collector is coaxially supported around said filament and between said anode and said cathode.

9. Apparatus as in claim **8** wherein: said cathode comprises the selected material; and said anode and said cathode are spaced apart by a distance approximately equal to the mean free path of the atoms to be sputtered from the cathode.

10. Apparatus as in claim **9** wherein: said anode and said filament are each to be operated at a reference potential; said collector is cylindrical and is to be operated at a selected positive potential relative to the reference potential of said anode; and said cathode is to be operated at a selected negative potential relative to the reference potential of said anode; whereby some of the electrons emitted from said filament collide with neutral atoms of said inert gas and produce positive ions that are attracted to said cathode where they sputter off atoms of the material to be deposited on said element.

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ROBERT K. MIHALEK, Primary Examiner

U.S. Cl. X.R.

204—192