

Cathodic Arc Vapor Deposition Apparatus (Annular Cathode)

BACKGROUND OF THE INVENTION

1. Technical Field

This invention relates to vapor deposition apparatus in general, and to cathodic arc vapor deposition apparatus in particular.

2. Background Information

Vapor deposition as a means for applying a coating to a substrate is a known art that includes processes such as chemical vapor deposition, physical vapor deposition, and cathodic arc vapor deposition. Chemical vapor deposition involves introducing reactive gaseous elements into a deposition chamber containing one or more substrates to be coated. Physical vapor deposition involves providing a source material and a substrate to be coated in a evacuated deposition chamber. The source material is converted into vapor by an energy input, such as heating by resistive, inductive, or electron beam means.

Cathodic arc vapor deposition involves a source material and a substrate to be coated placed in an evacuated deposition chamber. The chamber contains only a relatively small amount of gas. The negative lead of a direct current (DC) power supply is attached to the source material (hereinafter referred to as the "cathode") and the positive lead is attached to an anodic member. In many cases, the positive lead is attached to the deposition chamber, thereby making the chamber the anode. A arc-initiating trigger, at or near the same potential as the anode, contacts the cathode and subsequently moves away from the cathode. When the trigger is still in close proximity to the cathode, the difference in potential between the trigger and the cathode causes an arc of electricity to extend therebetween. As the trigger moves further away, the arc jumps between the cathode and the anodic chamber. The exact point, or points, where an arc touches the surface of the cathode



1 is referred to as a cathode spot. Absent a steering mechanism, a
2 cathode spot will move randomly about the surface of the cathode.

3 The energy deposited by the arc at a cathode spot is intense; on
4 the order of 10^5 to 10^7 amperes per square centimeter with a duration
5 of a few to several microseconds. The intensity of the energy raises
6 the local temperature of the cathode spot to approximately equal that of
7 the boiling point of the cathode material (at the evacuated chamber
8 pressure). As a result, cathode material at the cathode spot vaporizes
9 into a plasma containing atoms, molecules, ions, electrons, and
10 particles. Positively charged ions liberated from the cathode are
11 attracted toward any object within the deposition chamber having a
12 negative electric potential relative to the positively charged ion. Some
13 deposition processes maintain the substrate to be coated at the same
14 electric potential as the anode. Other processes use a biasing source to
15 lower the potential of the substrate and thereby make the substrate
16 relatively more attractive to the positively charged ions. In either case,
17 the substrate becomes coated with the vaporized material liberated from
18 the cathode. The rate of deposition, the coating density, and thickness
19 can be adjusted to satisfy the needs of the application.

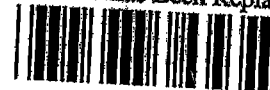
20 The random movement of the arc can sometimes lead to non-
21 uniform erosion of the cathode, which in turn can limit the useful life
22 of the cathode. To avoid non-uniform erosion, it is known to steer the
23 arc relative to the cathode. United States Patents Nos. 4,673,477,
24 4,849,088, and 5,037,522 are examples of patents that disclose
25 apparatus for steering an arc relative to a cathode. Some prior art
26 steers the arc by mechanically manipulating a magnetic field source
27 relative to the cathode. Other prior art steers the arc by electrically
28 manipulating the magnetic field source relative to the cathode. In both
29 these approaches, the speed of the arc relative to the cathode is limited
30 by the speed of the apparatus mechanically or electrically manipulating



1 the magnetic field source. Another limitation of these approaches is
2 the complexity of the hardware or switching mechanisms necessary to
3 manipulate the magnetic field source relative to the cathode. A person
4 of skill in the art will recognize that a production coating environment
5 is harsh and simplicity generally equates with reliability.

6 Many prior art cathodic arc coaters are not designed for
7 efficient, cost effective high volume use. In the example above, where
8 complex switching mechanisms and hardware are used to manipulate
9 magnetic field sources, cathode replacement can be cumbersome and
10 time consuming, and consequently costly. The same cost-problem
11 exists in most cathodic arc coaters that directly cool the cathode.
12 Direct cooling is generally accomplished by passing coolant between
13 the cathode and a manifold attached to the cathode, or by piping
14 coolant directly through the cathode. Either way, the cathode must be
15 machined to accept the manifold or piping, and the cost of the
16 consumable cathode is consequently increased (often dramatically). In
17 addition, some desirable cathode materials are not readily machinable.
18 Another problem with directly cooling the cathode is the labor required
19 to replace the cathode when its useful life has expired. In the previous
20 example where a manifold (or piping) is mechanically attached to the
21 cathode, the hardware (or piping) must be detached from the old
22 cathode and attached to a new one, and the deposition chamber
23 subsequently cleaned of coolant. For those applications which require
24 cathode replacement after each coating run, the cost of the cathode and
25 the labor to replace it can be considerable.

26 In short, what is needed is an apparatus for cathodic arc vapor
27 deposition of material on a substrate that operates efficiently, one
28 capable of consistently providing a high quality coatings on a substrate,
29 and one that operates cost effectively.



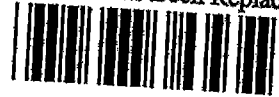
1 DISCLOSURE OF THE INVENTION

2 It is, therefore, an object of the present invention to provide an
3 apparatus for cathodic arc vapor deposition of material on a substrate
4 that operates in a cost effective manner.

5 It is another object of the present invention to provide an
6 apparatus for cathodic arc vapor deposition of material on a substrate
7 that consistently provides a high quality coating on a substrate.

8 According to the present invention, an apparatus for applying
9 material by cathodic arc vapor deposition to a substrate is provided
10 which includes a vessel, means for maintaining a vacuum in the vessel,
11 an annular cathode having a bore and an evaporative surface extending
12 between first and second end surfaces, means for selectively sustaining
13 an arc of electrical energy between the cathode and an anode, and
14 means for driving the arc around the evaporative surface. The means
15 for driving the arc is positioned within the cathode bore, and produces
16 a magnetic field that runs substantially parallel to the evaporative
17 surface. The annular cathode is disposed radially inside of, and aligned
18 with, the substrates inside the vessel.

19 An advantage of the present invention is that the present
20 invention apparatus for cathodic arc vapor deposition of material on a
21 substrate is designed to operate in a cost effective manner. One cost
22 effective characteristic of the present invention is the cathode. The
23 present invention cathode is annular and can be cut, for example, from
24 a cylindrical casting and drilled. The simply formed cathode requires
25 minimal expensive machining, thereby reducing the cost of the cathode
26 and the overall coating process. Another cost effective characteristic is
27 that the cathode is readily inserted in the vessel. Some prior art
28 cathodic arc coaters have cathodes that are fastened in place with the
29 deposition chamber, and/or have attached cooling apparatus. In either
30 case, the labor to install and remove the cathode undesirably increases



1 the cost of the coating process. Another cost effective characteristic of
2 the present invention is that the form of the used cathode facilitates
3 recycling. The used cathode is made of high quality material that has
4 been exposed to few, if any, contaminants. Consequently, the cathodes
5 have considerable scrap value that reduces the cost of the coating
6 process.

7 Another advantage of the present invention is that the magnetic
8 field source, and the positioning of the magnetic field source within the
9 cathode, help increase the efficiency of the coating process by
10 maximizing the amount of material that can be eroded from a particular
11 cathode.

12 Another advantage of the present invention is the simplicity and
13 reliability of the means for steering the arc around the cathode. The
14 means for steering the arc includes a magnetic field generator that does
15 not require a switching mechanism. The absence of a switching
16 mechanism increases the reliability of the steering means.

17 These and other objects, features and advantages of the present
18 invention will become apparent in light of the detailed description of
19 the best mode embodiment thereof, as illustrated in the accompanying
20 drawings.

21 BRIEF DESCRIPTION OF THE DRAWINGS

22 FIG.1 is a diagrammatic view of the present invention cathodic
23 arc vapor deposition apparatus.

24 FIG.2 is a diagrammatic partially sectioned view of an
25 embodiment of the contactor.

26 FIG.3 is a diagrammatic partially sectioned view of the
27 contactor shown in FIG.2, including magnetic field lines emanating
28 from the magnetic field generator.



1 FIG.4 is a diagrammatic partially sectioned view of another
2 embodiment of the contactor.

3 FIG.5 is a diagrammatic top view of a magnetic field generator.

4 BEST MODE FOR CARRYING OUT THE INVENTION

5 I. Apparatus

6 Referring to FIG.1, an apparatus 10 for cathodic arc vapor
7 deposition on a substrate 12, hereinafter referred to as a "cathodic arc
8 coater", is provided having a vessel 14, means 16 for maintaining a
9 vacuum in the vessel 14, a cathode 18, a contactor 20, an actuator 22
10 for selectively actuating the contactor 20 into electrical contact with the
11 cathode 18, and means 24 for sustaining an arc of electrical energy
12 between the cathode 18 and an anode 26. A coolant supply 28
13 maintains the apparatus 10 within acceptable temperatures by cycling
14 coolant through cooling passages 30,32 within the vessel 14 and
15 contactor 20. The means 16 for maintaining a vacuum in the vessel 14
16 preferably includes a mechanical rough vacuum pump 34 and a high
17 volume diffusion-type vacuum pump 36 piped to the interior of the
18 vessel 14. Other vacuum means may be used alternatively, however.
19 In the preferred embodiment, the cathode 18 is positioned on a platter
20 38 which can be readily inserted and removed from the vessel 14. The
21 cathode 18 is mounted in the center of the platter 38, and is electrically
22 insulated from the platter 38. A plurality of pivotly attached substrate
23 pedestals 39, attached to the platter 38, surround the cathode 18.

24 Referring to FIGS. 2 and 4, the cathode 18 is substantially
25 annular, having a first end surface 40, a second end surface 42, and an
26 evaporative surface 44 and bore 46 extending between the first 40 and
27 second 42 end surfaces. The end surfaces 40,42 are substantially
28 parallel with one another. A line 41, extending radially outward from
29 the centerline 43 of the cathode 18, positioned on or substantially near



1 the axial midpoint of the cathode 18, represents the axial midpoint of
2 the cathode 18. The material composition of the cathode 18 will
3 depend upon the material to be deposited. The axial length 48 of the
4 cathode 18 is preferably longer than the anticipated final axial length 50
5 of the erosion pattern 52 along the evaporative surface 44 of the
6 cathode 18. Keeping the erosion pattern 52 between the end surfaces
7 40,42 minimizes the possibility that the arc will leave the evaporative
8 surface 44 of the cathode 18.

9 Referring to FIGS. 1,2, and 4, the contactor 20 includes a head
10 54 attached to a hollow shaft 56. The head is positioned inside the
11 vessel 14 and the shaft 56 extends from the head 54 to outside the
12 vessel 14. An insulative disk 58 electrically insulates the contactor 20
13 from the vessel 14. The contactor 20 preferably includes a cooling
14 tube 60 coaxially positioned within the shaft 56, a coolant inlet port 62
15 connected to the cooling tube 60, and a coolant exit port 64 connected
16 to the passage 32 formed between the coaxial coolant tube 60 and shaft
17 56. The coaxial arrangement between the cooling tube 60 and the shaft
18 56 allows coolant to flow in the cooling tube 60 and exit via the
19 passage 32 between the shaft 56 and the cooling tube 60, or vice versa.
20 The actuator 22 for selectively actuating the contactor 20 into electrical
21 contact with the cathode 18 includes a pair of two-way actuating
22 cylinders 66 (hydraulic or pneumatic) acting between the vessel and a
23 shaft flange attached to the contactor shaft. Mechanical apparatus (not
24 shown) may be used in place of the actuating cylinders 66. A
25 commercially available controller (not shown) can be used to control
26 the position and force of the cylinders 66 (or mechanical apparatus).

27 Referring to FIG.2, in a first embodiment the contactor head 54
28 includes a tapered end 70. The tapered end 70 is selectively received
29 by a support block 72 that supports both a magnetic field generator 74
30 and the cathode 18. The actuator 22 selectively actuates the contactor



1 head 54 into and out of contact with the support block 72. The
2 magnetic field generator 74 is positioned within the bore 46 of the
3 cathode 18, substantially aligned with the axial midpoint 41 of the
4 cathode 18. The support block 72 electrically connects the contactor
5 20 to the cathode 18. An electrical insulator 76 and deflector shield 78
6 positioned on the side of the cathode 18 opposite the support block 72,
7 help keep contamination and debris off the cathode end surface 40.

8 Referring to FIG.4, in a second embodiment the contactor head
9 54 includes a cup 80 and a lid 82 that houses the magnetic field
10 generator 74. The cup 80 is received within the bore 46 of the cathode
11 18, such that the magnetic field generator 74 is substantially aligned
12 with the axial midpoint 41 of the cathode 18. The cup 80 makes
13 electrical contact with the cathode 18, thereby connecting the cathode
14 18 to the contactor 20. The actuator 22 selectively actuates the
15 contactor head 54 into and out of contact with the cathode 18. FIG.4
16 shows mating male 84 and female 86 surfaces on the cup 80 and within
17 the cathode bore 46, respectively. The mating male 84 and female 86
18 connection facilitates the contact necessary for an adequate electrical
19 contact. Other connection geometries may be used alternatively. In
20 both embodiments, the contactor shaft 56 and head 54 are fabricated
21 from an electrically conductive material such as a copper alloy.

22 The magnetic field generator 74 includes an annular magnet 88,
23 preferably segmented, which has a first 90 and second 92 end surface.
24 The polar ends of the annular magnet 88 are aligned with the end
25 surfaces 90,92; i.e., one end surface has an "N" polarity and the other
26 has an "S" polarity. In an alternative embodiment, the magnetic field
27 generator 74 includes a plurality of magnets 94 and a holder 96. The
28 magnets 94 are held by the holder 96, and are uniformly spaced around
29 the circumference of the cathode bore 46. Readily available
30 commercial cylindrical magnets may be used. FIG.5 shows an



1 embodiment having four (4) magnets 94 held within the holder 96,
2 although, the number of magnets 94 can be varied to accommodate the
3 process at hand.

4 Referring to FIG.1, the preferred embodiment further includes
5 apparatus 98 for rotating the magnetic field generator 74. The rotation
6 apparatus 98 includes a rod 100 extending through the coolant tube 60
7 and into the head 54 where it connects with the magnet holder 96. The
8 opposite end of the rod 100 is connected to a variable speed drive
9 motor 102 via a drive belt 104.

10 The cathodic arc coater 10 preferably includes a biasing source
11 106 for electrically biasing the substrates 12. A contact 108 electrically
12 connects the biasing source 106 and the platter 38. The substrates 12,
13 which are mechanically and electrically attached to the platter 38, are
14 consequently electrically connected to the biasing source 106. Other
15 means for electrically connecting the substrates 12 to the biasing source
16 106 may be used alternatively.

17 Deflector shields 110 are used throughout the cathodic arc
18 coater 10 to confine the vaporized cathode materials in the area of the
19 substrates 12. The deflector shields 110 attached to the vessel 14,
20 platter 38, and the contactor 20 also minimize undesirable material
21 build-up on those surfaces. In the preferred embodiment, the deflector
22 shields 110 attached to the vessel 14 are electrically connected to the
23 vessel 14 and are made of an electrically conductive material resistant
24 to corrosion, such as stainless steel.

25 The means 24 for sustaining an arc of electrical energy between
26 the cathode 18 and an anode 26 includes a direct current (D.C.) power
27 supply 112. In the preferred embodiment, the positive lead 114 of the
28 power supply 112 is connected to the vessel 14, thereby making the
29 vessel 14 act as an anode. The negative lead 116 of the power supply
30 112 is electrically connected to the contactor shaft 56. Alternative



embodiments may use an anode (not shown) disposed inside the vessel 14. An arc initiator 118 located inside the vessel 14 is maintained at or near the electrical potential of the vessel 14. The arc initiator 118 can be moved into and out of contact with the cathode 18.

II. Operation of the Apparatus

Referring to FIG.1, in the operation of the present invention cathodic arc coater 10, a cathode 18 is attached to the center of the platter 38 and a substrate 12 is attached to each rotatable pedestal 39 surrounding the cathode 18. The platter 38 is subsequently loaded into the vessel 14. The substrates 12 have been previously degreased and substantially cleaned, although each will likely have some molecular contaminant and oxidation remaining on its exterior surface. The actuating cylinders 66 subsequently actuate the contactor 20 into electrical contact with the cathode 18 and the vessel 14 is closed. The mechanical rough vacuum pump 34 is operated to evacuate the vessel 14 to a predetermined pressure. Once that pressure is reached, the high volume diffusion vacuum pump 36 further evacuates the vessel 14 to near vacuum conditions. The substrates 12 are then cleaned of any remaining contaminants and/or oxidation by a method such as "sputter cleaning". Sputter cleaning is a process well known in the art and will not be described in detail here. Other cleaning methods may be used alternatively. After the substrates 12 are cleaned, the contaminants are purged typically using an inert gas.

Prior to initiating an arc several steps are completed, including:

- (1) the substrates 12 are set to a particular bias via the biasing source 106, making them electrically attractive to positive ions emitted from the cathode 18;
- (2) the substrates 12 are put in motion at a particular rotational velocity;
- (3) the power supply 112 is set to establish an arc having a particular magnitude of current and voltage, but no arc is



1 initiated; (4) the vacuum pumps 34,36 establish and maintain a
2 particular vacuum pressure of gas within the vessel 14; and (5) coolant
3 is cycled through the cooling passages 30,32 within the vessel 14 and
4 contactor 20. Specific process parameters will depend upon factors
5 such as the substrate material, the material to be coated, and the
6 desired characteristics of the coating, etc.

7 Once the aforementioned steps have been completed, the arc
8 initiator 118 is brought into and out of contact with the evaporative
9 surface 44 of the cathode 18, causing an arc to jump between the arc
10 initiator 118 and the evaporative surface 44. The arc initiator 118 is
11 subsequently moved a distance away from the cathode 18, preferably
12 radially outside of the substrates 12. Once the arc initiator 118 is no
13 longer proximate the cathode 18, the arc jumps between the cathode 18
14 and the deflector shields 110 electrically connected to the anodic vessel
15 14 (or directly to the anodic vessel 14).

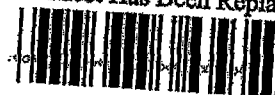
16 Referring to FIGS. 2-4, the magnetic field generator 74
17 positioned in the contactor 20 drives the arc along the evaporative
18 surface 44 of the cathode 18. The annular magnet 88 (or magnets 94)
19 produces a magnetic field, a portion of which runs substantially parallel
20 to the cathode evaporate surface 44. FIG.3 shows an approximation of
21 where the magnetic field lines are believed to run. A vector 124
22 representing the magnetic field extends between cathode end surfaces
23 40,42. The direction of the magnetic field vector depends upon the
24 orientation of the magnet poles. In the case of multiple magnets 94, all
25 magnet poles are oriented in like manner. A vector 126 representing
26 the electric arc, in contrast, extends away from the evaporative surface
27 44 in a substantially perpendicular direction. Together, the magnetic
28 field and the electric current of the arc create a force (the Hall effect)
29 on the arc that drives the arc a distance around the circumference of the
30 cathode 18. The dwell time of the arc at any particular cathode spot is



1 inversely related to the Hall effect force; i.e., an increase in the Hall
2 effect force, causes a decrease in the dwell time. In the embodiment
3 utilizing an annular magnet 88, the continuous annular magnetic field
4 and the current drive the arc along an arc path 128 circling the
5 evaporative surface 44 of the cathode 18. In the multiple magnet 94
6 embodiments where the magnets 94 are in close circumferential
7 proximity to one another, the individual magnetic fields collectively
8 drive the arc along the arc path 128. The number of magnets 94, the
9 relative spacing of magnetic fields emanating from magnets 94, and the
10 intensity of those magnetic fields can be adjusted to satisfy the
11 application at hand.

12 The symmetry of the magnetic field generator 74 relative to the
13 cathode helps increase the efficiency of the coating process by
14 maximizing the amount of material that can be eroded from a particular
15 cathode. Specifically, substantially aligning the magnetic field
16 generator 74 on the axial midpoint 41 of the cathode helps promote an
17 arc path 128 proximate the axial midpoint 41 of the cathode 18. In
18 addition, the symmetry of the magnetic field generator 74 relative to
19 the cathode 18 also appears to increase the parallelism of the magnetic
20 field lines relative to the cathode evaporative surface 44. Magnetic
21 field lines that extend a substantial distance along the evaporative
22 surface 44, parallel to the evaporative surface 44, appear to allow the
23 arc to symmetrically travel on both sides of the "average" arc path 128
24 position. As a result, the erosion pattern 52 grows axially during the
25 erosion process, thereby maximizing the amount of cathode material
26 that can be eroded from a particular annular cathode 18 and
27 consequently increasing the efficiency of the coating process.

28 FIGS. 2 and 4 shows an eroded cathode 18 in phantom,
29 substantially symmetrical about an arc path 128. In the embodiment
30 which includes the apparatus 98 for rotating the magnetic field



1 generator 74 (see FIGS. 1 and 4), rotation of the magnetic field
2 generator 74 within the contactor 20 helps promote uniform axial and
3 circumferential erosion of the cathode 18. The rotation distributes the
4 magnetic contribution of each magnet 94 around the circumference of
5 the cathode 18 as a function of time. It must be emphasized, however,
6 that rotation of the magnetic field generator 74 is not required to create
7 a circling arc. As stated above, the magnetic field of the annular
8 magnet 88 (or individual magnetic fields of the magnets 94 collectively)
9 forces the arc to circle the cathode evaporative surface 44.

10 Referring to FIG.1, the energy delivered by the arc causes the
11 material at the cathode spot to vaporize, thereby liberating atoms,
12 molecules, ions, electrons, and particles from the cathode 18. The
13 biased substrates 12 attract the ions, causing them to accelerate toward
14 the substrates 12. The ions strike the exterior surface of the substrates
15 12, attach, and collectively form a coating of the cathode material.
16 When a coating of sufficient thickness has been deposited on the
17 substrates 12, the power supply 112 is turned off and the arc
18 extinguished. The vessel 14 is purged with inert gas and brought to
19 ambient pressure. The contactor 20 is actuated out of contact with the
20 cathode 18 and the platter 38 is removed from the vessel 14. The
21 substrates 12 are subsequently removed from the platter 38 and new
22 substrates 12 attached. The loaded platter 38 is then inserted back into
23 the vessel 14 in the manner described earlier and the process repeated.

24 Although this invention has been shown and described with
25 respect to the detailed embodiments thereof, it will be understood by
26 those skilled in the art that various changes in form and detail thereof
27 may be made without departing from the spirit and the scope of the
28 invention. For example, a power supply 112 that simulates direct
29 current, such as one having an LCR circuit or other rectifying means,
30 may be used in place of a D.C. power supply. In another example,



1 FIG.4 shows a magnetic field generator 74 having a plurality of
2 magnets 94 and a holder 96. The annular magnet 88 shown in FIG.2
3 may be used in place of the plurality of magnets 94 and holder 96.



We claim:

1 1. An apparatus for applying material by cathodic arc vapor
2 deposition to substrates, comprising:
3 a vessel;
4 means for maintaining a vacuum in said vessel;
5 an annular cathode, having a first end surface, a second end
6 surface, an evaporative surface, and a bore, wherein said bore and said
7 evaporative surface extend between said first and second end surfaces;
8 wherein within said vessel, said annular cathode is disposed
9 radially inside of, and aligned with the substrates;
10 means for selectively sustaining an arc of electrical energy
11 between said cathode and an anode; and
12 means for driving said arc around said evaporative surface,
13 wherein said means for driving said arc is positioned within said bore,
14 and produces a magnetic field that runs substantially parallel to said
15 evaporative surface;
16 wherein said arc of electrical energy extending between said
17 cathode and said anode liberates a portion of said cathode which is
18 subsequently deposited on the substrate located radially outside said
19 cathode.

1 2. An apparatus according to claim 1, wherein said means for
2 sustaining an arc of electrical energy between said cathode and said
3 anode comprises:
4 a power supply, having a positive lead and a negative lead;
5 wherein said negative lead of said power supply is electrically
6 connected to said cathode, and said positive lead is electrically
7 connected to said vessel, thereby making said vessel act as said anode;
8 and
9 wherein said cathode is electrically insulated from said vessel.

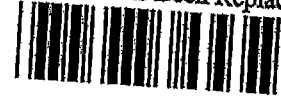
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- 1 3. An apparatus according to claim 1, wherein said means for
2 driving said arc around said evaporative surface comprises:
3 a magnetic field generator, having a plurality of magnets and a
4 holder;
5 wherein said magnetic field generator is positioned within said
6 cathode bore, and is substantially aligned with an axial midpoint of said
7 annular cathode.
- 1 4. An apparatus according to claim 3, wherein said holder holds
2 said magnets in a uniformly spaced arrangement around a
3 circumference of said bore.
- 1 5. An apparatus according to claim 1, wherein said means for
2 driving said arc around said evaporative surface comprises:
3 a magnetic field generator, having an annular magnet;
4 wherein said magnetic field generator is positioned within said
5 cathode bore, and is substantially aligned with an axial midpoint of said
6 annular cathode.
- 1 6. An apparatus according to claim 5, wherein said annular magnet
2 has a plurality of segments.
- 1 7. An apparatus according to claim 6, further comprising:
2 a protective coating, said coating encasing said magnets to
3 inhibit corrosion of said ferromagnetic center piece and said magnets.
- 1 8. An apparatus according to claim 1, further comprising:
2 a contactor, electrically connected to said power supply; and





3 an actuator, wherein said actuator selectively actuates said
4 contactor into electrical contact with said cathode, and thereby
5 electrically connects said cathode to said power supply.

1 9. An apparatus according to claim 8, wherein said contactor
2 comprises:

3 a head, positioned inside said vessel;
4 a hollow shaft, attached to said head, extending from said head
5 to outside said vessel.

1 10. An apparatus according to claim 9, wherein said contactor
2 further comprises means for cooling said shaft and head.

1 11. An apparatus according to claim 10, wherein said cooling means
2 comprises:

3 a cooling tube, positioned inside said hollow shaft, wherein a
4 passage is formed between said cooling tube and said hollow shaft;
5 a coolant source, connected to said cooling tube and said
6 passage, for providing a coolant within said contactor.

1 12. An apparatus according to claim 11, further comprising:
2 a platter;

3 wherein one or more said substrates are connected to said
4 platter; and

5 wherein said cathode is mounted on said platter, and electrically
6 insulated from said platter;

7 wherein said platter is loaded into said vessel prior to deposition
8 and removed subsequently.

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1 13. An apparatus according to claim 12, wherein said platter further
2 comprises:

3 a plurality of pedestals, pivotly attached to said platter, and one
4 or more of said substrates are attached to each said pedestal;
5 wherein said pedestals and said attached substrates, can be
6 rotated to change orientation relative to said cathode.

1 14. An apparatus according to claim 9, wherein said means for
2 driving said arc around said evaporative surface comprises:

3 a magnetic field generator, having a plurality of magnets and a
4 holder, disposed within said head;

5 wherein said head is selectively actuated into said cathode bore,
6 to a position where said magnetic field generator is substantially aligned
7 with an axial midpoint of said annular cathode.

1 15. An apparatus according to claim 14, wherein said holder holds
2 said magnets in a uniformly spaced arrangement around a
3 circumference of said bore.



1 16. An apparatus according to claim 14, further comprising:
2 means for rotating said magnetic field generator within said
3 head.

1 17. An apparatus according to claim 9, wherein said means for
2 driving said arc around said evaporative surface comprises:

3 a magnetic field generator, having an annular magnet, disposed
4 within said head;

5 wherein said head is selectively actuated into said cathode bore,
6 to a position where said magnetic field generator is substantially aligned
7 with an axial midpoint of said annular cathode.



- 1 18. An apparatus according to claim 17, wherein said annular
2 magnet has a plurality of segments.
- 1 19. An apparatus according to claim 8, wherein said means for
2 driving said arc around said evaporative surface comprises:
3 a magnetic field generator, having a plurality of magnets and a
4 holder;
5 wherein said magnetic field generator is positioned within said
6 cathode bore, and is substantially aligned with an axial midpoint of said
7 annular cathode.
- 1 20. An apparatus according to claim 19, wherein said holder holds
2 said magnets in a uniformly spaced arrangement around a
3 circumference of said bore.
- 1 21. An apparatus according to claim 8, wherein said means for
2 driving said arc around said evaporative surface comprises:
3 a magnetic field generator, having an annular magnet;
4 wherein said magnetic field generator is positioned within said
5 cathode bore, and is substantially aligned with an axial midpoint of said
6 annular cathode.
- 1 22. An apparatus according to claim 21, wherein said annular
2 magnet has a plurality of segments.

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1 ABSTRACT OF THE DISCLOSURE

2 According to the present invention, an apparatus for applying
3 material by cathodic arc vapor deposition to a substrate is provided
4 which includes a vessel, apparatus for maintaining a vacuum in the
5 vessel, an annular cathode having a bore and an evaporative surface
6 extending between first and second end surfaces, apparatus for
7 selectively sustaining an arc of electrical energy between the cathode
8 and an anode, and apparatus for driving the arc around the evaporative
9 surface. The apparatus for driving the arc is positioned within the
10 cathode bore, and produces a magnetic field that runs substantially
11 parallel to the evaporative surface. The annular cathode is disposed
12 radially inside of, and aligned with, the substrates inside the vessel.

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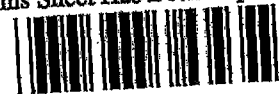
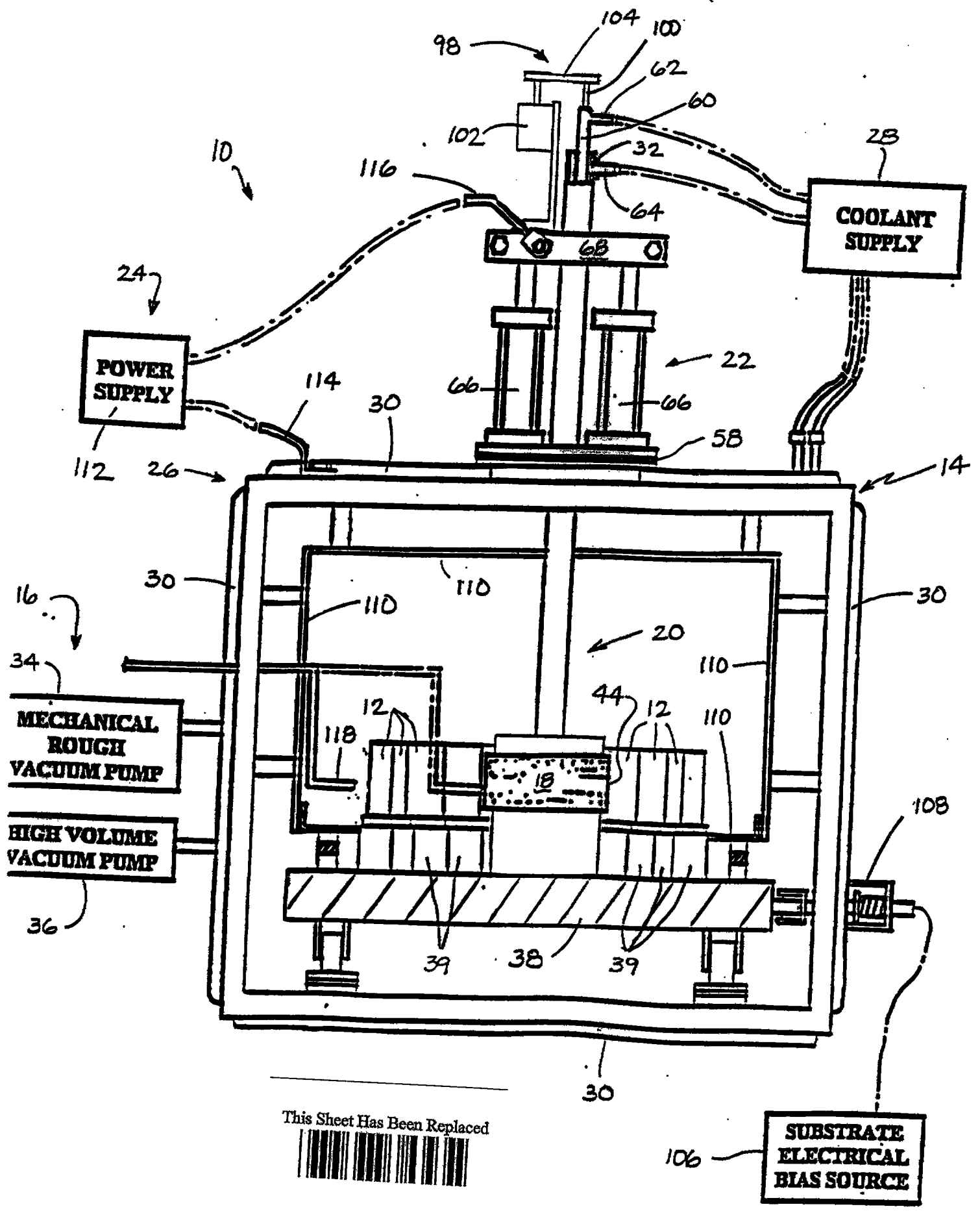


FIG. 1



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SUBSTRATE
ELECTRICAL
BIAS SOURCE

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FIG. 2

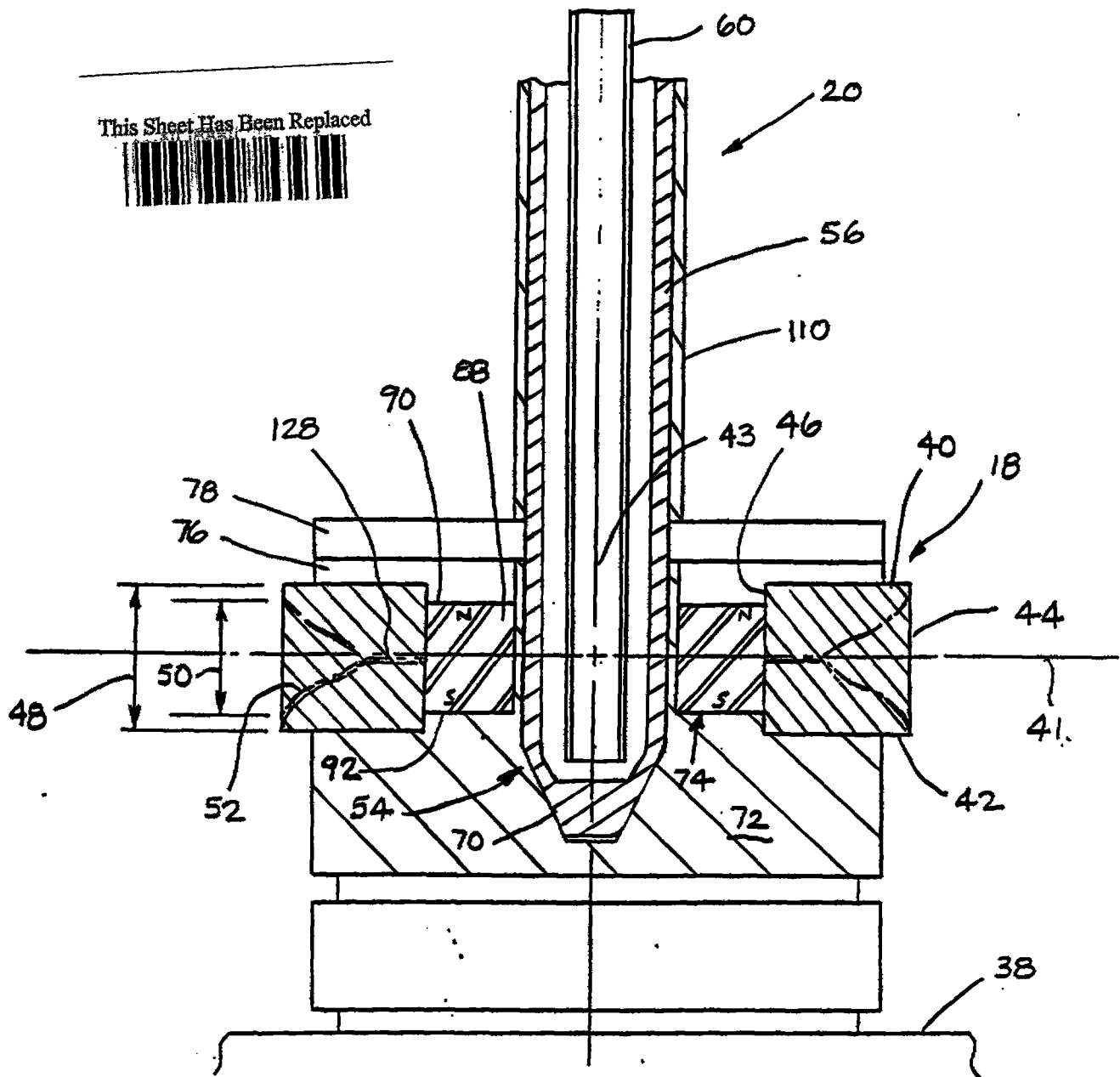
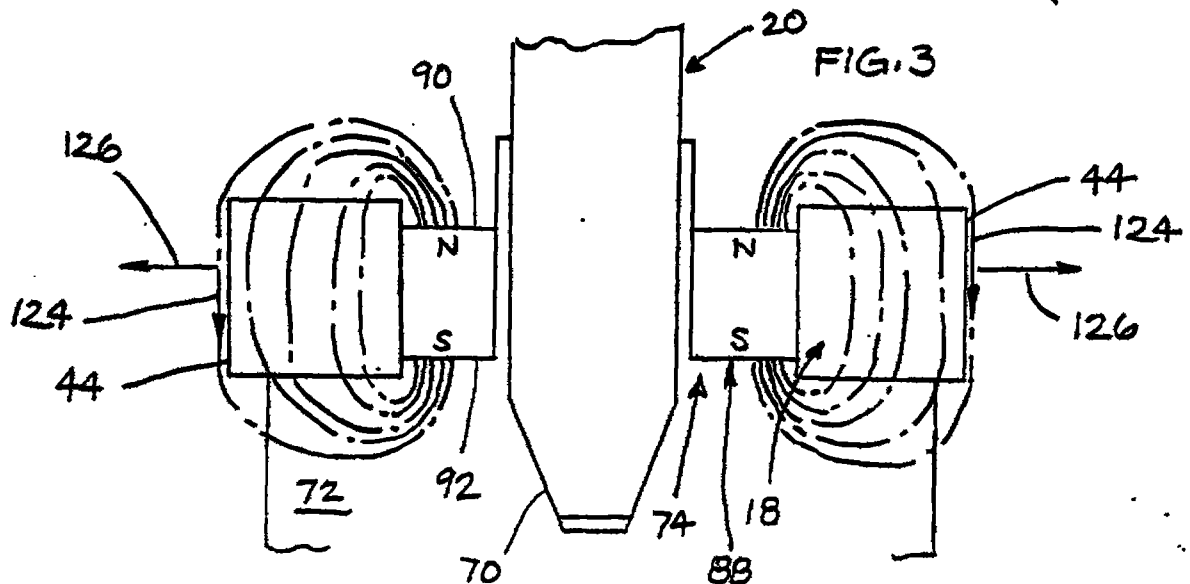


FIG. 3



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FIG. 4

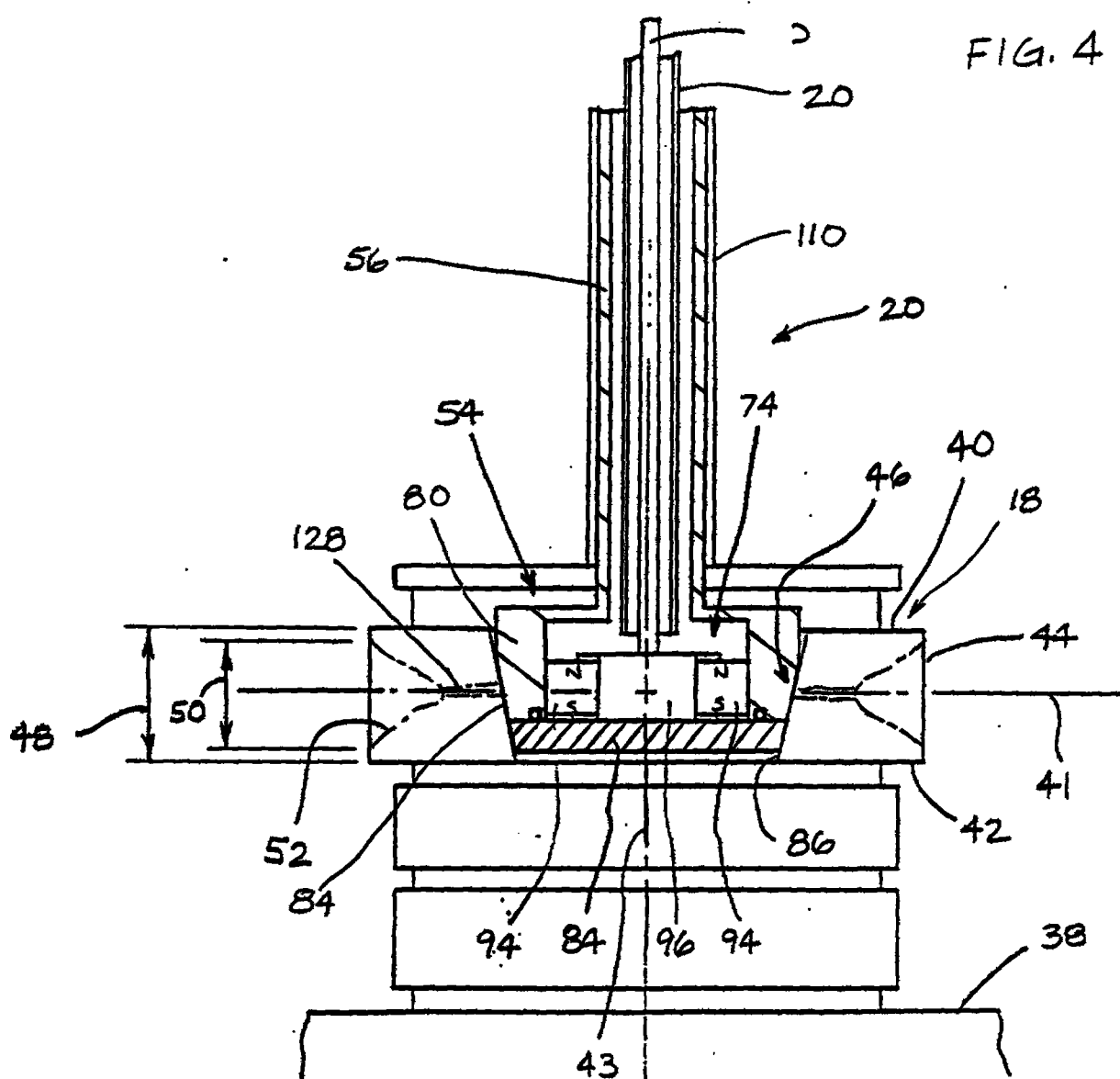
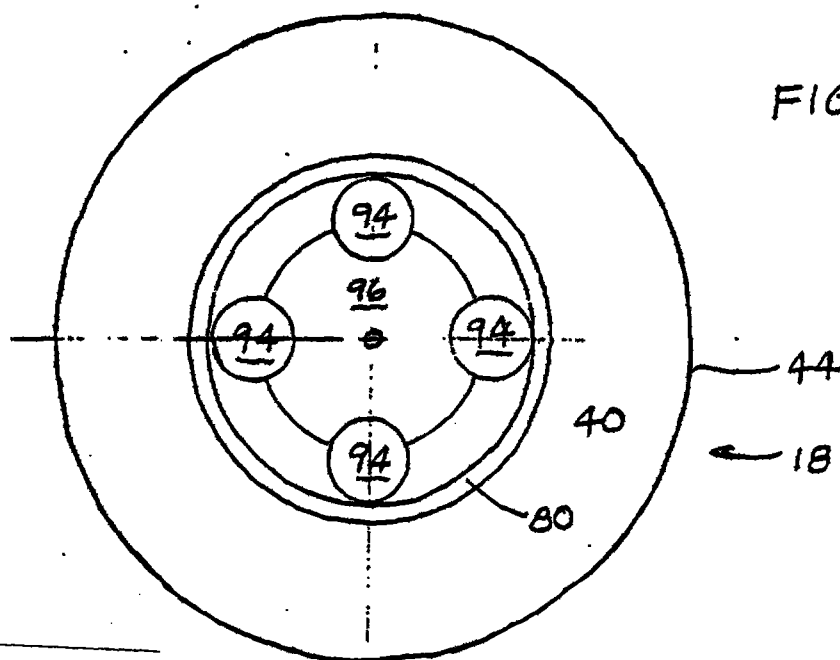


FIG. 5



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Cathodic Arc Vapor Deposition Apparatus (Annular Cathode)

BACKGROUND OF THE INVENTION

1. Technical Field

This invention relates to vapor deposition apparatus in general, and to cathodic arc vapor deposition apparatus in particular.

2. Background Information

Vapor deposition as a means for applying a coating to a substrate is a known art that includes processes such as chemical vapor deposition, physical vapor deposition, and cathodic arc vapor deposition. Chemical vapor deposition involves introducing reactive gaseous elements into a deposition chamber containing one or more substrates to be coated. Physical vapor deposition involves providing a source material and a substrate to be coated in a evacuated deposition chamber. The source material is converted into vapor by an energy input, such as heating by resistive, inductive, or electron beam means.

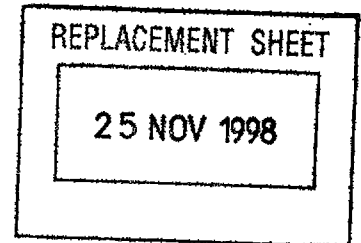
Cathodic arc vapor deposition involves a source material and a substrate to be coated placed in an evacuated deposition chamber. The chamber contains only a relatively small amount of gas. The negative lead of a direct current (DC) power supply is attached to the source material (hereinafter referred to as the "cathode") and the positive lead is attached to an anodic member. In many cases, the positive lead is attached to the deposition chamber, thereby making the chamber the anode. A arc-initiating trigger, at or near the same potential as the anode, contacts the cathode and subsequently moves away from the cathode. When the trigger is still in close proximity to the cathode, the difference in potential between the trigger and the cathode causes an arc of electricity to extend therebetween. As the trigger moves further away, the arc jumps between the cathode and the anodic chamber. The exact point, or points, where an arc touches the surface of the cathode

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1 is referred to as a cathode spot. Absent a steering mechanism, a
2 cathode spot will move randomly about the surface of the cathode.

3 The energy deposited by the arc at a cathode spot is intense; on
4 the order of 10^5 to 10^7 amperes per square centimeter with a duration
5 of a few to several microseconds. The intensity of the energy raises
6 the local temperature of the cathode spot to approximately equal that of
7 the boiling point of the cathode material (at the evacuated chamber
8 pressure). As a result, cathode material at the cathode spot vaporizes
9 into a plasma containing atoms, molecules, ions, electrons, and
10 particles. Positively charged ions liberated from the cathode are
11 attracted toward any object within the deposition chamber having a
12 negative electric potential relative to the positively charged ion. Some
13 deposition processes maintain the substrate to be coated at the same
14 electric potential as the anode. Other processes use a biasing source to
15 lower the potential of the substrate and thereby make the substrate
16 relatively more attractive to the positively charged ions. In either case,
17 the substrate becomes coated with the vaporized material liberated from
18 the cathode. The rate of deposition, the coating density, and thickness
19 can be adjusted to satisfy the needs of the application.

20 The random movement of the arc can sometimes lead to non-
21 uniform erosion of the cathode, which in turn can limit the useful life
22 of the cathode. To avoid non-uniform erosion, it is known to steer the
23 arc relative to the cathode. United States Patents Nos. 4,673,477,
24 4,849,088, and 5,037,522 are examples of patents that disclose
25 apparatus for steering an arc relative to a cathode. Some prior art
26 steers the arc by mechanically manipulating a magnetic field source
27 relative to the cathode. Other prior art steers the arc by electrically
28 manipulating the magnetic field source relative to the cathode. In both
29 these approaches, the speed of the arc relative to the cathode is limited
30 by the speed of the apparatus mechanically or electrically manipulating



1 the magnetic field source. Another limitation of these approaches is
2 the complexity of the hardware or switching mechanisms necessary to
3 manipulate the magnetic field source relative to the cathode. A person
4 of skill in the art will recognize that a production coating environment
5 is harsh and simplicity generally equates with reliability.

6 Many prior art cathodic arc coaters are not designed for
7 efficient, cost effective high volume use. In the example above, where
8 complex switching mechanisms and hardware are used to manipulate
9 magnetic field sources, cathode replacement can be cumbersome and
10 time consuming, and consequently costly. The same cost-problem
11 exists in most cathodic arc coaters that directly cool the cathode.
12 Direct cooling is generally accomplished by passing coolant between
13 the cathode and a manifold attached to the cathode, or by piping
14 coolant directly through the cathode. Either way, the cathode must be
15 machined to accept the manifold or piping, and the cost of the
16 consumable cathode is consequently increased (often dramatically). In
17 addition, some desirable cathode materials are not readily machinable.
18 Another problem with directly cooling the cathode is the labor required
19 to replace the cathode when its useful life has expired. In the previous
20 example where a manifold (or piping) is mechanically attached to the
21 cathode, the hardware (or piping) must be detached from the old
22 cathode and attached to a new one, and the deposition chamber
23 subsequently cleaned of coolant. For those applications which require
24 cathode replacement after each coating run, the cost of the cathode and
25 the labor to replace it can be considerable.

26 In short, what is needed is an apparatus for cathodic arc vapor
27 deposition of material on a substrate that operates efficiently, one
28 capable of consistently providing a high quality coatings on a substrate,
29 and one that operates cost effectively.

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1 DISCLOSURE OF THE INVENTION

2 It is, therefore, an object of the present invention to provide an
3 apparatus for cathodic arc vapor deposition of material on a substrate
4 that operates in a cost effective manner.

5 It is another object of the present invention to provide an
6 apparatus for cathodic arc vapor deposition of material on a substrate
7 that consistently provides a high quality coating on a substrate.

8 According to the present invention, an apparatus for applying
9 material by cathodic arc vapor deposition to a substrate is provided
10 which includes a vessel, means for maintaining a vacuum in the vessel,
11 an annular cathode having a bore and an evaporative surface extending
12 between first and second end surfaces, means for selectively sustaining
13 an arc of electrical energy between the cathode and an anode, and
14 means for driving the arc around the evaporative surface. The means
15 for driving the arc is positioned within the cathode bore, and produces
16 a magnetic field that runs substantially parallel to the evaporative
17 surface. The annular cathode is disposed radially inside of, and aligned
18 with, the substrates inside the vessel.

19 An advantage of the present invention is that the present
20 invention apparatus for cathodic arc vapor deposition of material on a
21 substrate is designed to operate in a cost effective manner. One cost
22 effective characteristic of the present invention is the cathode. The
23 present invention cathode is annular and can be cut, for example, from
24 a cylindrical casting and drilled. The simply formed cathode requires
25 minimal expensive machining, thereby reducing the cost of the cathode
26 and the overall coating process. Another cost effective characteristic is
27 that the cathode is readily inserted in the vessel. Some prior art
28 cathodic arc coaters have cathodes that are fastened in place with the
29 deposition chamber, and/or have attached cooling apparatus. In either
30 case, the labor to install and remove the cathode undesirably increases

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1 the cost of the coating process. Another cost effective characteristic of
2 the present invention is that the form of the used cathode facilitates
3 recycling. The used cathode is made of high quality material that has
4 been exposed to few, if any, contaminants. Consequently, the cathodes
5 have considerable scrap value that reduces the cost of the coating
6 process.

7 Another advantage of the present invention is that the magnetic
8 field source, and the positioning of the magnetic field source within the
9 cathode, help increase the efficiency of the coating process by
10 maximizing the amount of material that can be eroded from a particular
11 cathode.

12 Another advantage of the present invention is the simplicity and
13 reliability of the means for steering the arc around the cathode. The
14 means for steering the arc includes a magnetic field generator that does
15 not require a switching mechanism. The absence of a switching
16 mechanism increases the reliability of the steering means.

17 These and other objects, features and advantages of the present
18 invention will become apparent in light of the detailed description of
19 the best mode embodiment thereof, as illustrated in the accompanying
20 drawings.

21 BRIEF DESCRIPTION OF THE DRAWINGS

22 FIG.1 is a diagrammatic view of the present invention cathodic
23 arc vapor deposition apparatus.

24 FIG.2 is a diagrammatic partially sectioned view of an
25 embodiment of the contactor.

26 FIG.3 is a diagrammatic partially sectioned view of the
27 contactor shown in FIG.2, including magnetic field lines emanating
28 from the magnetic field generator.

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FIG.4 is a diagrammatic partially sectioned view of another embodiment of the contactor.

FIG.5 is a diagrammatic top view of a magnetic field generator.

BEST MODE FOR CARRYING OUT THE INVENTION

I. Apparatus

Referring to FIG.1, an apparatus 10 for cathodic arc vapor deposition on a substrate 12, hereinafter referred to as a "cathodic arc coater", is provided having a vessel 14, means 16 for maintaining a vacuum in the vessel 14, a cathode 18, a contactor 20, an actuator 22 for selectively actuating the contactor 20 into electrical contact with the cathode 18, and means 24 for sustaining an arc of electrical energy between the cathode 18 and an anode 26. A coolant supply 28 maintains the apparatus 10 within acceptable temperatures by cycling coolant through cooling passages 30,32 within the vessel 14 and contactor 20. The means 16 for maintaining a vacuum in the vessel 14 preferably includes a mechanical rough vacuum pump 34 and a high volume diffusion-type vacuum pump 36 piped to the interior of the vessel 14. Other vacuum means may be used alternatively, however. In the preferred embodiment, the cathode 18 is positioned on a platter 38 which can be readily inserted and removed from the vessel 14. The cathode 18 is mounted in the center of the platter 38, and is electrically insulated from the platter 38. A plurality of pivotly attached substrate pedestals 39, attached to the platter 38, surround the cathode 18.

Referring to FIGS. 2 and 4, the cathode 18 is substantially annular, having a first end surface 40, a second end surface 42, and an evaporative surface 44 and bore 46 extending between the first 40 and second 42 end surfaces. The end surfaces 40,42 are substantially parallel with one another. A line 41, extending radially outward from the centerline 43 of the cathode 18, positioned on or substantially near

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1 the axial midpoint of the cathode 18, represents the axial midpoint of
2 the cathode 18. The material composition of the cathode 18 will
3 depend upon the material to be deposited. The axial length 48 of the
4 cathode 18 is preferably longer than the anticipated final axial length 50
5 of the erosion pattern 52 along the evaporative surface 44 of the
6 cathode 18. Keeping the erosion pattern 52 between the end surfaces
7 40,42 minimizes the possibility that the arc will leave the evaporative
8 surface 44 of the cathode 18.

9 Referring to FIGS. 1,2, and 4, the contactor 20 includes a head
10 54 attached to a hollow shaft 56. The head is positioned inside the
11 vessel 14 and the shaft 56 extends from the head 54 to outside the
12 vessel 14. An insulative disk 58 electrically insulates the contactor 20
13 from the vessel 14. The contactor 20 preferably includes a cooling
14 tube 60 coaxially positioned within the shaft 56, a coolant inlet port 62
15 connected to the cooling tube 60, and a coolant exit port 64 connected
16 to the passage 32 formed between the coaxial coolant tube 60 and shaft
17 56. The coaxial arrangement between the cooling tube 60 and the shaft
18 56 allows coolant to flow in the cooling tube 60 and exit via the
19 passage 32 between the shaft 56 and the cooling tube 60, or vice versa.
20 The actuator 22 for selectively actuating the contactor 20 into electrical
21 contact with the cathode 18 includes a pair of two-way actuating
22 cylinders 66 (hydraulic or pneumatic) acting between the vessel and a
23 shaft flange attached to the contactor shaft. Mechanical apparatus (not
24 shown) may be used in place of the actuating cylinders 66. A
25 commercially available controller (not shown) can be used to control
26 the position and force of the cylinders 66 (or mechanical apparatus).

7 Referring to FIG.2, in a first embodiment the contactor head 54
8 includes a tapered end 70. The tapered end 70 is selectively received
9 by a support block 72 that supports both a magnetic field generator 74
0 and the cathode 18. The actuator 22 selectively actuates the contactor

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1 head 54 into and out of contact with the support block 72. The
2 magnetic field generator 74 is positioned within the bore 46 of the
3 cathode 18, substantially aligned with the axial midpoint 41 of the
4 cathode 18. The support block 72 electrically connects the contactor
5 20 to the cathode 18. An electrical insulator 76 and deflector shield 78
6 positioned on the side of the cathode 18 opposite the support block 72,
7 help keep contamination and debris off the cathode end surface 40.

8 Referring to FIG.4, in a second embodiment the contactor head
9 54 includes a cup 80 and a lid 82 that houses the magnetic field
10 generator 74. The cup 80 is received within the bore 46 of the cathode
11 18, such that the magnetic field generator 74 is substantially aligned
12 with the axial midpoint 41 of the cathode 18. The cup 80 makes
13 electrical contact with the cathode 18, thereby connecting the cathode
14 18 to the contactor 20. The actuator 22 selectively actuates the
15 contactor head 54 into and out of contact with the cathode 18. FIG.4
16 shows mating male 84 and female 86 surfaces on the cup 80 and within
17 the cathode bore 46, respectively. The mating male 84 and female 86
18 connection facilitates the contact necessary for an adequate electrical
19 contact. Other connection geometries may be used alternatively. In
20 both embodiments, the contactor shaft 56 and head 54 are fabricated
21 from an electrically conductive material such as a copper alloy.

22 The magnetic field generator 74 includes an annular magnet 88,
23 preferably segmented, which has a first 90 and second 92 end surface.
24 The polar ends of the annular magnet 88 are aligned with the end
25 surfaces 90,92; i.e., one end surface has an "N" polarity and the other
26 has an "S" polarity. In an alternative embodiment, the magnetic field
27 generator 74 includes a plurality of magnets 94 and a holder 96. The
28 magnets 94 are held by the holder 96, and are uniformly spaced around
29 the circumference of the cathode bore 46. Readily available
30 commercial cylindrical magnets may be used. FIG.5 shows an

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1 embodiment having four (4) magnets 94 held within the holder 96,
2 although, the number of magnets 94 can be varied to accommodate the
3 process at hand.

4 Referring to FIG.1, the preferred embodiment further includes
5 apparatus 98 for rotating the magnetic field generator 74. The rotation
6 apparatus 98 includes a rod 100 extending through the coolant tube 60
7 and into the head 54 where it connects with the magnet holder 96. The
8 opposite end of the rod 100 is connected to a variable speed drive
9 motor 102 via a drive belt 104.

10 The cathodic arc coater 10 preferably includes a biasing source
11 106 for electrically biasing the substrates 12. A contact 108 electrically
12 connects the biasing source 106 and the platter 38. The substrates 12,
13 which are mechanically and electrically attached to the platter 38, are
14 consequently electrically connected to the biasing source 106. Other
15 means for electrically connecting the substrates 12 to the biasing source
16 106 may be used alternatively.

17 Deflector shields 110 are used throughout the cathodic arc
18 coater 10 to confine the vaporized cathode materials in the area of the
19 substrates 12. The deflector shields 110 attached to the vessel 14,
20 platter 38, and the contactor 20 also minimize undesirable material
21 build-up on those surfaces. In the preferred embodiment, the deflector
22 shields 110 attached to the vessel 14 are electrically connected to the
23 vessel 14 and are made of an electrically conductive material resistant
24 to corrosion, such as stainless steel.

25 The means 24 for sustaining an arc of electrical energy between
26 the cathode 18 and an anode 26 includes a direct current (D.C.) power
27 supply 112. In the preferred embodiment, the positive lead 114 of the
28 power supply 112 is connected to the vessel 14, thereby making the
29 vessel 14 act as an anode. The negative lead 116 of the power supply
30 112 is electrically connected to the contactor shaft 56. Alternative

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embodiments may use an anode (not shown) disposed inside the vessel 14. An arc initiator 118 located inside the vessel 14 is maintained at or near the electrical potential of the vessel 14. The arc initiator 118 can be moved into and out of contact with the cathode 18.

II. Operation of the Apparatus

Referring to FIG.1, in the operation of the present invention cathodic arc coater 10, a cathode 18 is attached to the center of the platter 38 and a substrate 12 is attached to each rotatable pedestal 39 surrounding the cathode 18. The platter 38 is subsequently loaded into the vessel 14. The substrates 12 have been previously degreased and substantially cleaned, although each will likely have some molecular contaminant and oxidation remaining on its exterior surface. The actuating cylinders 66 subsequently actuate the contactor 20 into electrical contact with the cathode 18 and the vessel 14 is closed. The mechanical rough vacuum pump 34 is operated to evacuate the vessel 14 to a predetermined pressure. Once that pressure is reached, the high volume diffusion vacuum pump 36 further evacuates the vessel 14 to near vacuum conditions. The substrates 12 are then cleaned of any remaining contaminants and/or oxidation by a method such as "sputter cleaning". Sputter cleaning is a process well known in the art and will not be described in detail here. Other cleaning methods may be used alternatively. After the substrates 12 are cleaned, the contaminants are purged typically using an inert gas.

Prior to initiating an arc several steps are completed, including:

- (1) the substrates 12 are set to a particular bias via the biasing source 106, making them electrically attractive to positive ions emitted from the cathode 18;
- (2) the substrates 12 are put in motion at a particular rotational velocity;
- (3) the power supply 112 is set to establish an arc having a particular magnitude of current and voltage, but no arc is

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1 initiated; (4) the vacuum pumps 34,36 establish and maintain a
2 particular vacuum pressure of gas within the vessel 14; and (5) coolant
3 is cycled through the cooling passages 30,32 within the vessel 14 and
4 contactor 20. Specific process parameters will depend upon factors
5 such as the substrate material, the material to be coated, and the
6 desired characteristics of the coating, etc.

7 Once the aforementioned steps have been completed, the arc
8 initiator 118 is brought into and out of contact with the evaporative
9 surface 44 of the cathode 18, causing an arc to jump between the arc
10 initiator 118 and the evaporative surface 44. The arc initiator 118 is
11 subsequently moved a distance away from the cathode 18, preferably
12 radially outside of the substrates 12. Once the arc initiator 118 is no
13 longer proximate the cathode 18, the arc jumps between the cathode 18
14 and the deflector shields 110 electrically connected to the anodic vessel
15 14 (or directly to the anodic vessel 14).

16 Referring to FIGS. 2-4, the magnetic field generator 74
17 positioned in the contactor 20 drives the arc along the evaporative
18 surface 44 of the cathode 18. The annular magnet 88 (or magnets 94)
19 produces a magnetic field, a portion of which runs substantially parallel
20 to the cathode evaporate surface 44. FIG.3 shows an approximation of
21 where the magnetic field lines are believed to run. A vector 124
22 representing the magnetic field extends between cathode end surfaces
23 40,42. The direction of the magnetic field vector depends upon the
24 orientation of the magnet poles. In the case of multiple magnets 94, all
25 magnet poles are oriented in like manner. A vector 126 representing
26 the electric arc, in contrast, extends away from the evaporative surface
27 44 in a substantially perpendicular direction. Together, the magnetic
28 field and the electric current of the arc create a force (the Hall effect)
29 on the arc that drives the arc a distance around the circumference of the
30 cathode 18. The dwell time of the arc at any particular cathode spot is

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1 inversely related to the Hall effect force; i.e., an increase in the Hall
2 effect force, causes a decrease in the dwell time. In the embodiment
3 utilizing an annular magnet 88, the continuous annular magnetic field
4 and the current drive the arc along an arc path 128 circling the
5 evaporative surface 44 of the cathode 18. In the multiple magnet 94
6 embodiments where the magnets 94 are in close circumferential
7 proximity to one another, the individual magnetic fields collectively
8 drive the arc along the arc path 128. The number of magnets 94, the
9 relative spacing of magnetic fields emanating from magnets 94, and the
10 intensity of those magnetic fields can be adjusted to satisfy the
11 application at hand.

12 The symmetry of the magnetic field generator 74 relative to the
13 cathode helps increase the efficiency of the coating process by
14 maximizing the amount of material that can be eroded from a particular
15 cathode. Specifically, substantially aligning the magnetic field
16 generator 74 on the axial midpoint 41 of the cathode helps promote an
17 arc path 128 proximate the axial midpoint 41 of the cathode 18. In
18 addition, the symmetry of the magnetic field generator 74 relative to
19 the cathode 18 also appears to increase the parallelism of the magnetic
20 field lines relative to the cathode evaporative surface 44. Magnetic
21 field lines that extend a substantial distance along the evaporative
22 surface 44, parallel to the evaporative surface 44, appear to allow the
23 arc to symmetrically travel on both sides of the "average" arc path 128
24 position. As a result, the erosion pattern 52 grows axially during the
25 erosion process, thereby maximizing the amount of cathode material
26 that can be eroded from a particular annular cathode 18 and
27 consequently increasing the efficiency of the coating process.

28 FIGS. 2 and 4 shows an eroded cathode 18 in phantom,
29 substantially symmetrical about an arc path 128. In the embodiment
30 which includes the apparatus 98 for rotating the magnetic field

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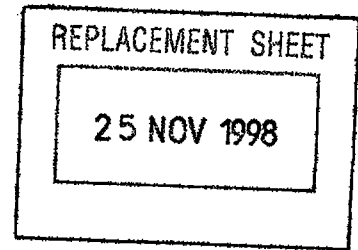
1 generator 74 (see FIGS. 1 and 4), rotation of the magnetic field
2 generator 74 within the contactor 20 helps promote uniform axial and
3 circumferential erosion of the cathode 18. The rotation distributes the
4 magnetic contribution of each magnet 94 around the circumference of
5 the cathode 18 as a function of time. It must be emphasized, however,
6 that rotation of the magnetic field generator 74 is not required to create
7 a circling arc. As stated above, the magnetic field of the annular
8 magnet 88 (or individual magnetic fields of the magnets 94 collectively)
9 forces the arc to circle the cathode evaporative surface 44.

0 Referring to FIG.1, the energy delivered by the arc causes the
1 material at the cathode spot to vaporize, thereby liberating atoms,
2 molecules, ions, electrons, and particles from the cathode 18. The
3 biased substrates 12 attract the ions, causing them to accelerate toward
4 the substrates 12. The ions strike the exterior surface of the substrates
5 12, attach, and collectively form a coating of the cathode material.
6 When a coating of sufficient thickness has been deposited on the
7 substrates 12, the power supply 112 is turned off and the arc
8 extinguished. The vessel 14 is purged with inert gas and brought to
9 ambient pressure. The contactor 20 is actuated out of contact with the
10 cathode 18 and the platter 38 is removed from the vessel 14. The
11 substrates 12 are subsequently removed from the platter 38 and new
12 substrates 12 attached. The loaded platter 38 is then inserted back into
13 the vessel 14 in the manner described earlier and the process repeated.

14 Although this invention has been shown and described with
15 respect to the detailed embodiments thereof, it will be understood by
16 those skilled in the art that various changes in form and detail thereof
17 may be made without departing from the spirit and the scope of the
18 invention. For example, a power supply 112 that simulates direct
19 current, such as one having an LCR circuit or other rectifying means,
20 may be used in place of a D.C. power supply. In another example,

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- 1 FIG.4 shows a magnetic field generator 74 having a plurality of
- 2 magnets 94 and a holder 96. The annular magnet 88 shown in FIG.2
- 3 may be used in place of the plurality of magnets 94 and holder 96.



We claim:

1. An apparatus for applying material by cathodic arc vapor deposition to substrates, comprising:
 - a vessel;
 - means for maintaining a vacuum in said vessel;
 - an annular cathode, having a first end surface, a second end surface, an evaporative surface, and a bore, wherein said bore and said evaporative surface extend between said first and second end surfaces; wherein within said vessel, said annular cathode is disposed radially inside of, and aligned with the substrates;
 - means for selectively sustaining an arc of electrical energy between said cathode and an anode; and
 - means for driving said arc around said evaporative surface, wherein said means for driving said arc is positioned within said bore, and produces a magnetic field that runs substantially parallel to said evaporative surface;
 - wherein said arc of electrical energy extending between said cathode and said anode liberates a portion of said cathode which is subsequently deposited on the substrate located radially outside said cathode.
2. An apparatus according to claim 1, wherein said means for sustaining an arc of electrical energy between said cathode and said anode comprises:
 - a power supply, having a positive lead and a negative lead;
 - wherein said negative lead of said power supply is electrically connected to said cathode, and said positive lead is electrically connected to said vessel, thereby making said vessel act as said anode;
 - and
 - wherein said cathode is electrically insulated from said vessel.



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1 3. An apparatus according to claim 1, wherein said means for
2 driving said arc around said evaporative surface comprises:
3 a magnetic field generator, having a plurality of magnets and a
4 holder;
5 wherein said magnetic field generator is positioned within said
6 cathode bore, and is substantially aligned with an axial midpoint of said
7 annular cathode.

1 4. An apparatus according to claim 3, wherein said holder holds
2 said magnets in a uniformly spaced arrangement around a
3 circumference of said bore.



1 5. An apparatus according to claim 1, wherein said means for
2 driving said arc around said evaporative surface comprises:
3 a magnetic field generator, having an annular magnet;
4 wherein said magnetic field generator is positioned within said
5 cathode bore, and is substantially aligned with an axial midpoint of said
6 annular cathode.

1 6. An apparatus according to claim 5, wherein said annular magnet
2 has a plurality of segments.

1 7. An apparatus according to claim 6, further comprising:
2 a protective coating, said coating encasing said magnets to
3 inhibit corrosion of said ferromagnetic center piece and said magnets.

1 8. An apparatus according to claim 1, further comprising:
2 a contactor, electrically connected to said power supply; and

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17

3 an actuator, wherein said actuator selectively actuates said
4 contactor into electrical contact with said cathode, and thereby
5 electrically connects said cathode to said power supply.

1 9. An apparatus according to claim 8, wherein said contactor
2 comprises:

3 a head, positioned inside said vessel;
4 a hollow shaft, attached to said head, extending from said head
5 to outside said vessel.

1 10. An apparatus according to claim 9, wherein said contactor
2 further comprises means for cooling said shaft and head.

1 11. An apparatus according to claim 10, wherein said cooling means
2 comprises:

3 a cooling tube, positioned inside said hollow shaft, wherein a
4 passage is formed between said cooling tube and said hollow shaft;
5 a coolant source, connected to said cooling tube and said
6 passage, for providing a coolant within said contactor.

1 12. An apparatus according to claim 11, further comprising:

2 a platter;
3 wherein one or more said substrates are connected to said
4 platter; and
5 wherein said cathode is mounted on said platter, and electrically
6 insulated from said platter;
7 wherein said platter is loaded into said vessel prior to deposition
8 and removed subsequently.

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1 13. An apparatus according to claim 12, wherein said platter further
2 comprises:

3 a plurality of pedestals, pivotly attached to said platter, and one
4 or more of said substrates are attached to each said pedestal;

5 wherein said pedestals and said attached substrates, can be
6 rotated to change orientation relative to said cathode.

1 14. An apparatus according to claim 9, wherein said means for
2 driving said arc around said evaporative surface comprises:

3 a magnetic field generator, having a plurality of magnets and a
4 holder, disposed within said head;

5 wherein said head is selectively actuated into said cathode bore,
6 to a position where said magnetic field generator is substantially aligned
7 with an axial midpoint of said annular cathode.

1 15. An apparatus according to claim 14, wherein said holder holds
2 said magnets in a uniformly spaced arrangement around a
3 circumference of said bore.



1 16. An apparatus according to claim 14, further comprising:
2 means for rotating said magnetic field generator within said
3 head.

1 17. An apparatus according to claim 9, wherein said means for
2 driving said arc around said evaporative surface comprises:

3 a magnetic field generator, having an annular magnet, disposed
4 within said head;

5 wherein said head is selectively actuated into said cathode bore,
6 to a position where said magnetic field generator is substantially aligned
7 with an axial midpoint of said annular cathode.

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- 1 18. An apparatus according to claim 17, wherein said annular
2 magnet has a plurality of segments.
- 1 19. An apparatus according to claim 8, wherein said means for
2 driving said arc around said evaporative surface comprises:
3 a magnetic field generator, having a plurality of magnets and a
4 holder;
5 wherein said magnetic field generator is positioned within said
6 cathode bore, and is substantially aligned with an axial midpoint of said
7 annular cathode.
- 1 20. An apparatus according to claim 19, wherein said holder holds
2 said magnets in a uniformly spaced arrangement around a
3 circumference of said bore.
- 1 21. An apparatus according to claim 8, wherein said means for
2 driving said arc around said evaporative surface comprises:
3 a magnetic field generator, having an annular magnet;
4 wherein said magnetic field generator is positioned within said
5 cathode bore, and is substantially aligned with an axial midpoint of said
6 annular cathode.
- 1 22. An apparatus according to claim 21, wherein said annular
2 magnet has a plurality of segments.

THIS SHEET HAS BEEN
REPLACED

REPLACEMENT SHEET

25 NOV 1998

Cathodic Arc Vapor Deposition Apparatus (Annular Cathode)

ABSTRACT OF THE DISCLOSURE

According to the present invention, an apparatus for applying material by cathodic arc vapor deposition to a substrate is provided which includes a vessel, apparatus for maintaining a vacuum in the vessel, an annular cathode having a bore and an evaporative surface extending between first and second end surfaces, apparatus for selectively sustaining an arc of electrical energy between the cathode and an anode, and apparatus for driving the arc around the evaporative surface. The apparatus for driving the arc is positioned within the cathode bore, and produces a magnetic field that runs substantially parallel to the evaporative surface. The annular cathode is disposed radially inside of, and aligned with, the substrates inside the vessel.

(Figure 1)

This Sheet Has Been Replaced



25 NOV 1998

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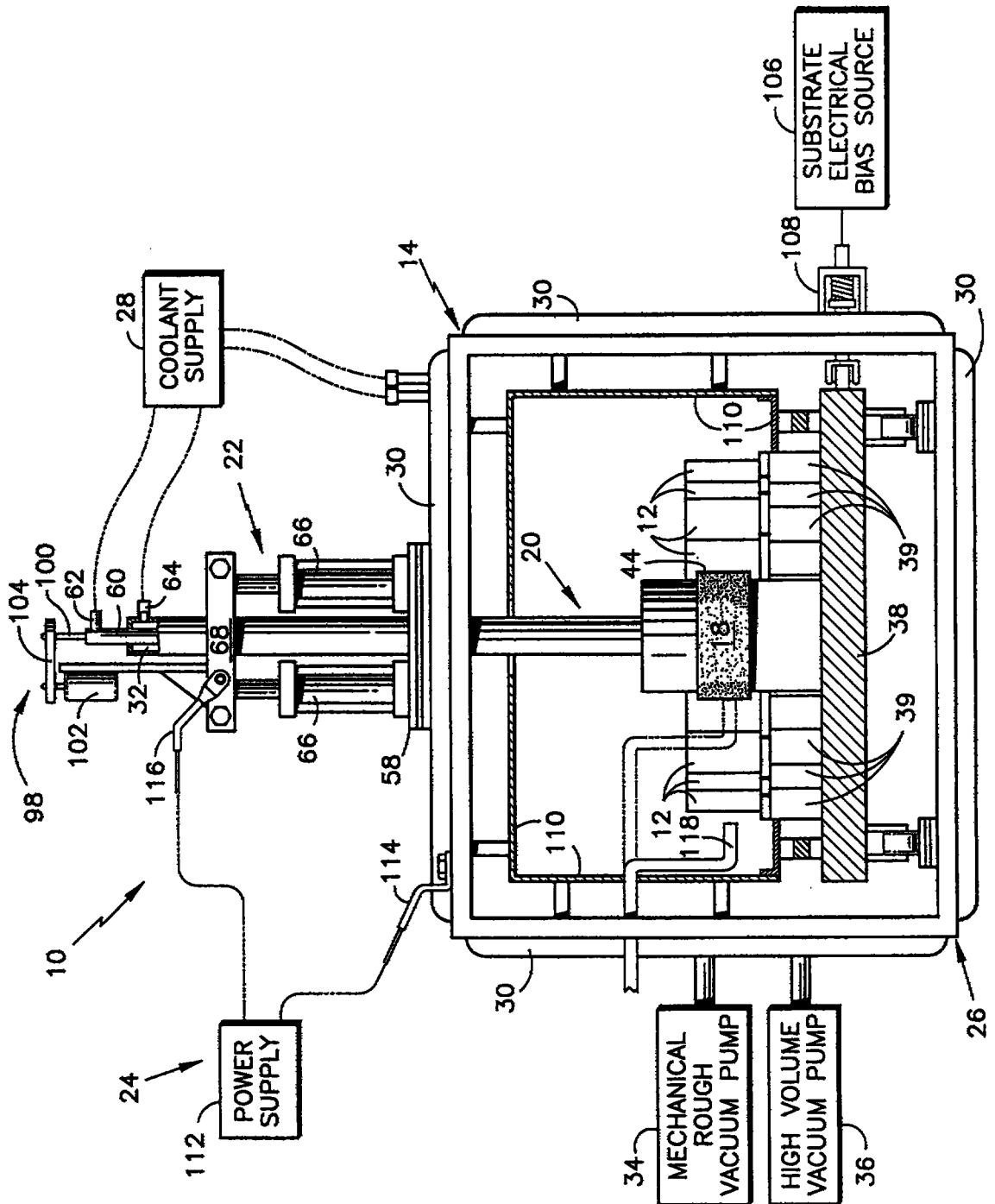


FIG.1

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FIG. 2

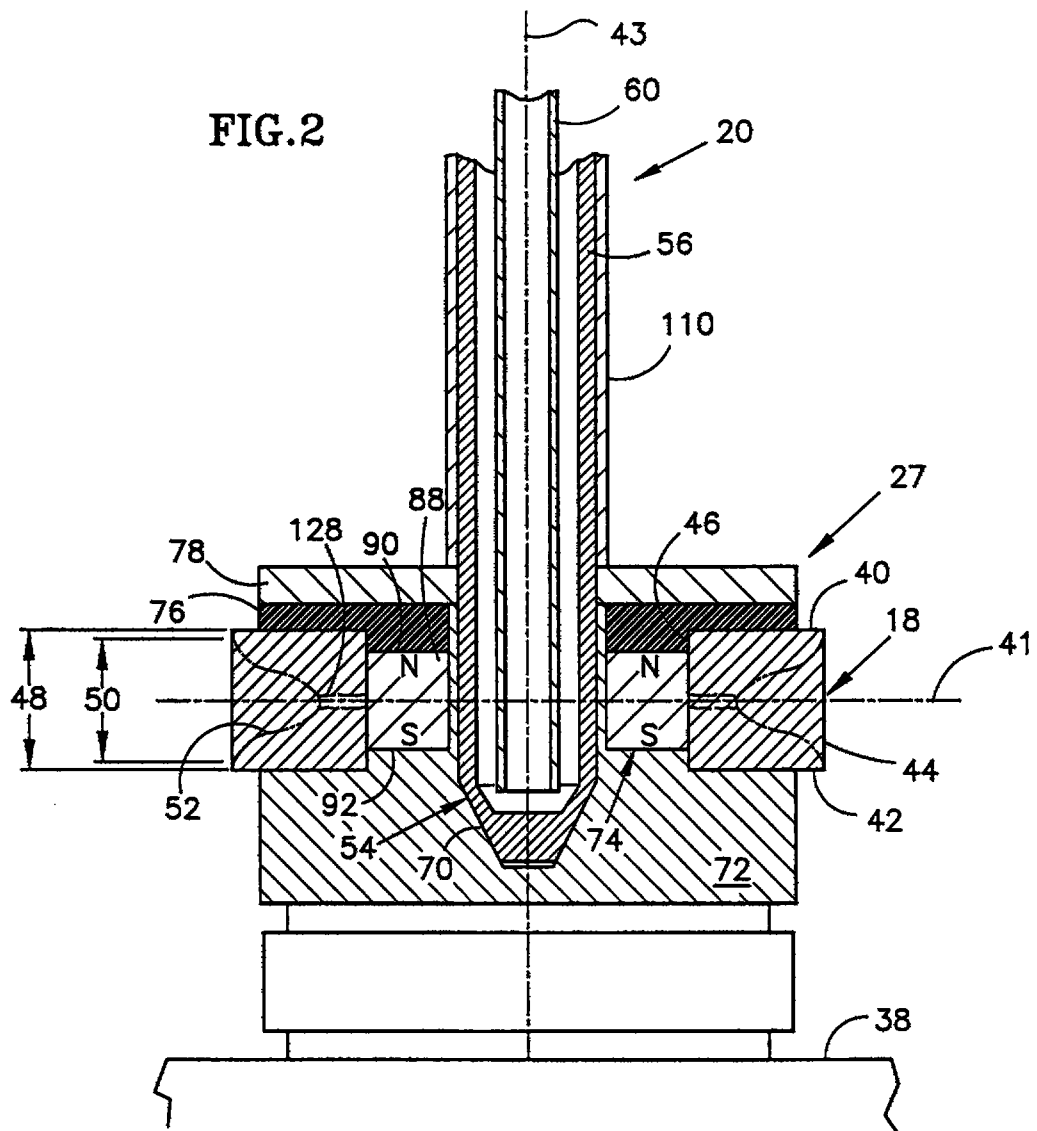


FIG. 3

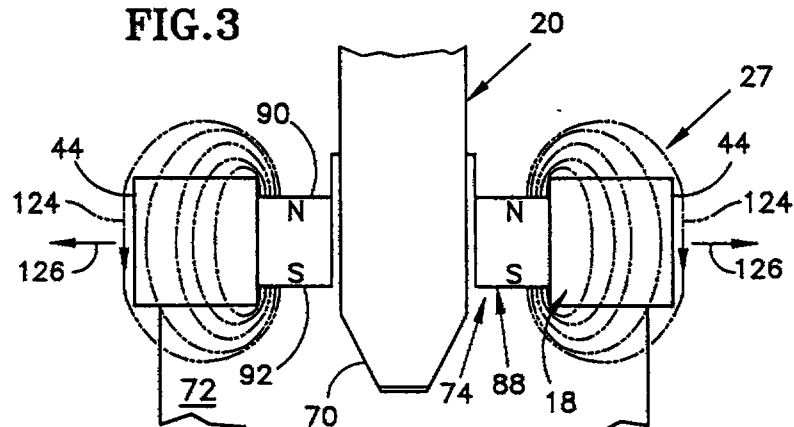


FIG.4

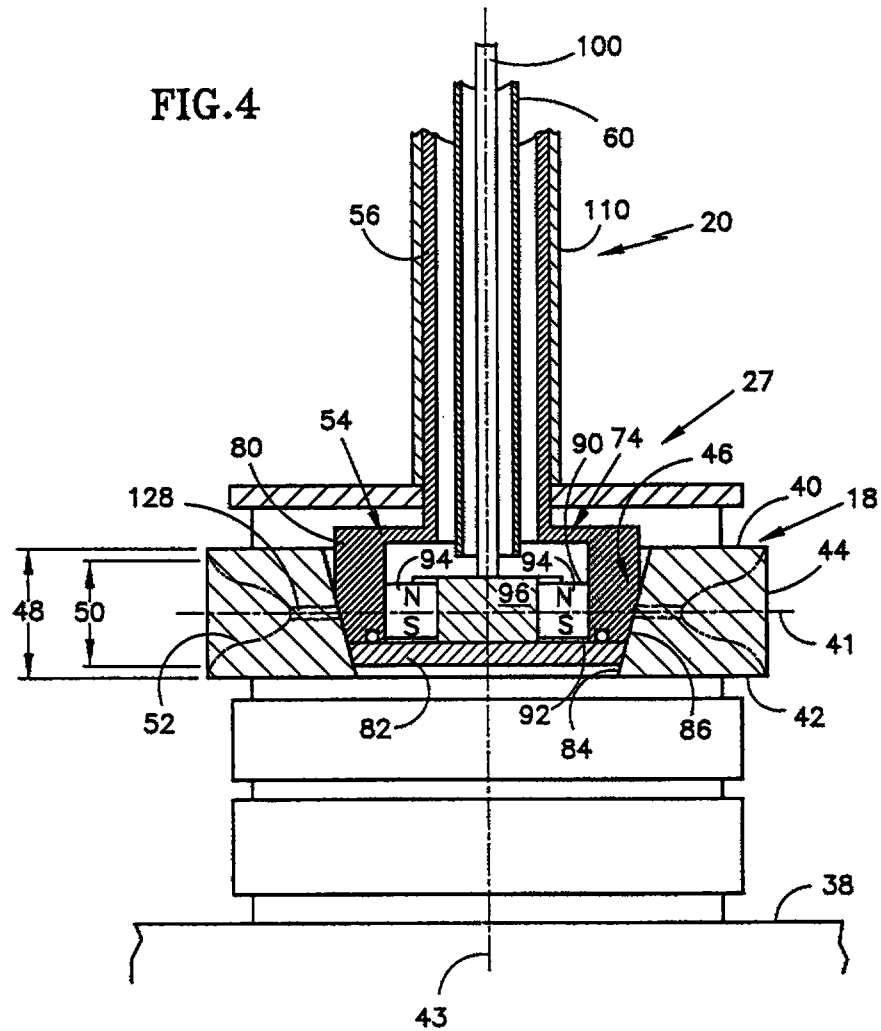
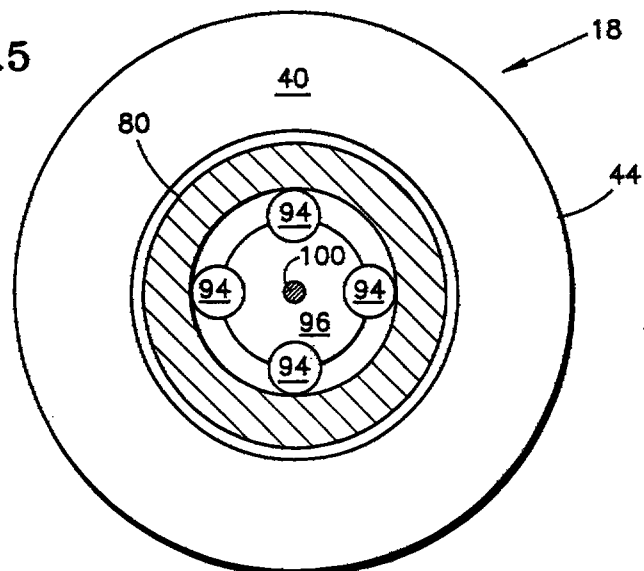


FIG.5





TEXT OF THE ABSTRACT

CATHODIC ARC VAPOR DEPOSITIONS APPARATUS (ANNULAR CATHODE)

According to the present invention, an apparatus for applying material by cathodic arc vapor deposition to a substrate (12) is provided which includes a vessel (14), apparatus (16) for maintaining a vacuum in the vessel (14), and annular cathode (18) having a bore and an evaporative surface (44) extending between first and second end surfaces, apparatus (24) for selectively sustaining an arc of electrical energy between the cathode (18) and an anode (26), and apparatus for driving the arc around the evaporative surface. The apparatus for driving the arc is positioned within the cathode bore, and produces a magnetic field that runs substantially parallel to the evaporative surface. The annular cathode is disposed radially inside of, and aligned with, the substrates inside the vessel.

Figure 1.

