

Cathodic Arc Vapor Deposition Apparatus

This Sheet Has Been Replaced



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. An arc-initiating trigger, at or near the same potential as the anode, contacts and moves away from the cathode. When the trigger is 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 is referred to as a cathode spot. Absent a steering

THIS SHEET HAS BEEN
REPLACED



1 mechanism, a cathode spot will move randomly about the surface of the
2 cathode.

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

20 Presently available cathodic arc coaters typically use a cooled
21 cathode fixed in place within the coater. One cooling scheme provides a
22 manifold attached to the cathode that permits the passage of coolant
23 between the cathode and manifold. Another scheme uses coolant piping
24 connected to a hollow cathode. A problem with either scheme is that the
25 cathode must be machined to accept the manifold or piping. Not all
26 cathode materials are amenable to machining and even where possible,
27 machining adds significantly to the cost of the consumable cathode.
28 Another problem with directly cooling the cathode is the labor required
29 to replace the cathode when its useful life has expired. In the previous
30 example where a manifold (or piping) is mechanically attached to the



1 cathode, the manifold (or piping) must be detached from the old cathode
2 and attached to a new one, and the deposition chamber subsequently
3 cleaned of coolant. For those applications which require cathode
4 replacement after each coating run, the labor costs and down time can be
5 considerable. Still another problem with direct cathode cooling is
6 leakage. Coolant leakage occurring during deposition can contaminate the
7 substrates being coated and require extensive cleaning within the
8 deposition chamber. Airfoils for gas turbine engines are an example of
9 an expensive substrate to be coated; one where it would be a distinct
10 advantage to minimize or eliminate losses due to contamination.

11 In short, what is needed is an apparatus for cathodic arc vapor
12 deposition of material on a substrate that operates efficiently, one capable
13 of repeatably providing a high quality coatings on a substrate, and one
14 that operates cost effectively.

15 DISCLOSURE OF THE INVENTION

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

19 It is another object of the present invention to provide an apparatus
20 for cathodic arc vapor deposition of material on a substrate that repeatably
21 provides a high quality coating on a substrate.

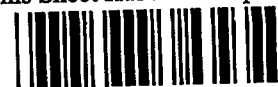
22 According to the present invention, an apparatus for applying
23 material by cathodic arc vapor deposition to a substrate is provided which
24 includes a vessel, means for maintaining a vacuum in the vessel, a
25 cathode, a contactor, means for selectively sustaining an arc of electrical
26 energy between the cathode and an anode, and an actuator. The cathode
27 and contactor are positioned inside the vessel, and the contactor is
28 electrically connected to the means for selectively sustaining an arc of
29 electrical energy. The actuator selectively actuates the contactor into



1 electrical contact with the cathode, and thereby electrically connects the
2 cathode to the means for sustaining an arc of electrical energy. The arc
3 of electrical energy extending between the cathode and the anode liberates
4 cathode material, which is subsequently deposited on the substrate located
5 inside the vessel.

6 An advantage of the present invention is that the present invention
7 apparatus for cathodic arc vapor deposition of material on a substrate is
8 designed to operate in a cost effective manner. One cost effective
9 characteristic of the present invention is the cathode. The present
10 invention cathode is preferably disk-shaped and can be cut, for example,
11 from a cylindrical casting. The simply formed cathode requires minimal
12 expensive machining, thereby reducing the cost of the cathode and the
13 overall coating process. Another cost effective characteristic is that the
14 cathode is indirectly cooled. Presently available cathodic arc coaters that
15 pass coolant in direct contact with the cathode (i.e., direct cooling)
16 generally require machining to accept a manifold or piping. The
17 machining significantly increases the cost of the consumable cathode.
18 Another cost effective characteristic is that the cathode is readily inserted
19 in the vessel. Some prior art cathodic arc coaters have cathodes that are
20 fastened in place with the deposition chamber, and/or have attached
21 cooling apparatus. In either case, the labor to install and remove the
22 cathode undesirably increases the cost of the coating process. Another
23 cost effective characteristic of the present invention is that the form of the
24 used cathode facilitates recycling. The used cathode is made of high
25 quality material that has been exposed to few, if any, contaminants.
26 Consequently, the cathodes have considerable scrap value that reduces the
27 cost of the coating process.

28 Another advantage of the present invention is that high quality
29 coatings can be consistently produced. The platter provides for rotation
30 of the substrates to promote uniform deposition, and the indirect cooling



1 of the cathode via the contactor minimizes the chance of coolant
2 contamination. Hence, high quality coatings can be consistently deposited
3 on substrates.

4 These and other objects, features and advantages of the present
5 invention will become apparent in light of the detailed description of the
6 best mode embodiment thereof, as illustrated in the accompanying
7 drawings.

8 BRIEF DESCRIPTION OF THE DRAWINGS

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

11 FIG.2 is a top diagrammatic view of the present invention platter.

12 FIG.3 is a side view of the platter shown in FIG.2.

13 FIG. 4 is a diagrammatic cross-sectional view of a contactor.

14 BEST MODE FOR CARRYING OUT THE INVENTION

15 I. Apparatus

16 Referring to FIG.1, an apparatus 10 for cathodic arc vapor
17 deposition on a substrate 12, hereinafter referred to as a "cathodic arc
18 coater", is provided having a vessel 14, means 16 for maintaining a
19 vacuum in the vessel 14, a cathode 18, a contactor 20, an actuator 22 for
20 selectively actuating the contactor 20 into electrical contact with the
21 cathode 18, and means 24 for sustaining an arc of electrical energy
22 between the cathode 18 and an anode 26. A coolant supply 28 maintains
23 the coater 10 within acceptable temperatures by cycling coolant through
24 passages 30,32 within the vessel 14 and contactor 20, respectively. In the
25 preferred embodiment, the means 16 for maintaining a vacuum in the
26 vessel 14 includes a mechanical rough vacuum pump 34 and a high-
27 volume diffusion-type vacuum pump 36 piped to the interior of the vessel
28 14. Other vacuum means may be used alternatively.



1 Referring to FIG.2, the cathode 18 is a substantially cylindrical
2 disk having a first end surface 38, a second end surface 40, and an
3 evaporative surface 42 extending therebetween. The end surfaces 38,40
4 are substantially parallel with one another. The material composition of
5 the cathode 18 will depend upon the material to be deposited, and in most
6 cases the cathode 18 can be cut from a cast rod. The axial length 44 of
7 the evaporative surface 42 is preferably longer than the anticipated final
8 axial length 46 of the erosion pattern 48 along the evaporative surface 42.
9 Keeping the erosion pattern 48 between the end surfaces 38,40 minimizes
10 the possibility that the arc will leave the evaporative surface 42 of the
11 cathode 18.

12 Referring to FIGS. 1, 3 and 4, in the preferred embodiment the
13 cathode 18 is positioned on a removable platter 50. The platter 50
14 includes a tray 52, a plurality of pedestals 54, and means 56 for rotating
15 the pedestals 54. The cathode 18 is mounted in the center of the platter
16 50, on top of a plurality of spacers 58 (see also FIG.2) separated by
17 electrical insulators 60. Adapters 62 attached to the pedestals 54 can be
18 used to align the substrates 12 radially outside the cathode 18.

19 The means 56 for rotating the pedestals 54 includes a center gear
20 64 engaged with a plurality of pedestal gears 66. Each pedestal gear 66
21 is fixed to a pedestal 54, and the center and pedestal gears 64,66 are
22 pivotly attached to the tray 52. The center gear 64 is driven by a gear 68
23 positioned inside the vessel 14. A shaft extending through the vessel wall
24 connects the gear 68 to a drive unit 70.

25 Referring to FIGS. 1 and 2, the contactor 20 includes a head 72
26 attached to a shaft 74, and means 76 for cooling the contactor 20. The
27 head 72 is positioned inside the vessel 14 and the shaft 74 extends from
28 the head 72 to outside the vessel 14. An insulative disk 78 (FIG.1)
29 electrically insulates the contactor 20 from the vessel 14. The means 76
30 for cooling the contactor 20 includes a cooling tube 80 coaxially



1 positioned within the shaft 74, a coolant inlet port 82 connected to the
2 cooling tube 80, and a coolant exit port 84 connected to the passage 32
3 formed between the coaxial coolant tube 80 and shaft 74. The coaxial
4 arrangement between the cooling tube 80 and the shaft 74 allows coolant
5 to flow in the cooling tube 80 and exit via the passage 32 between the
6 shaft 74 and the cooling tube 80, or vice versa. The head 72 includes a
7 cup 86 and a shaft flange 88. The shaft flange 88 is fixed to the shaft 74
8 and the cup 86 is fixed to the shaft flange 88. The cup 86, shaft flange
9 88, and shaft 74 are fabricated from an electrically conductive material
10 such as a copper alloy. The preferred embodiment of the head 72 further
11 includes a magnetic field generator 90.

12 Referring to FIG.1, the actuator 22 for selectively actuating the
13 contactor 20 into electrical contact with the cathode 18 includes a pair of
14 two-way actuating cylinders 92 (hydraulic or pneumatic) for acting
15 between the vessel 14 and a shaft flange 94 attached to the contactor shaft
16 74. Mechanical apparatus (not shown) may be used in place of the
17 actuating cylinders 92. A commercially available controller can be used
18 to control the position and force of the cylinders (or mechanical
19 apparatus).

20 In the preferred embodiment, the cathodic arc coater 10 includes
21 a biasing source 96 for electrically biasing the substrates 12. A contact-
22 type switch 98 electrically connects the biasing source 96 and the platter
23 50. The substrates 12, which are mechanically and electrically attached
24 to the platter 50, are consequently electrically connected to the biasing
25 source 96. Other means for electrically connecting the substrates 12 to
26 the biasing source 96 may be used alternatively.

27 Deflector shields 98 are used throughout the cathodic arc coater 10
28 to confine the vaporized cathode materials in the area of the substrates 12.
29 The shields 98 attached to the vessel 14, platter 50, spacers 58, and
30 contactor 20 help minimize undesirable material build-up on those



1 surfaces. In the preferred embodiment, the deflector shields 98 attached
2 to the vessel 14 are electrically connected to the vessel 14 and are made
3 of an electrically conductive material such as stainless steel.

4 The means 24 for sustaining an arc of electrical energy between
5 the cathode 18 and an anode 26 includes a direct current (D.C.) power
6 supply 100. In the preferred embodiment, the positive lead 106 of the
7 power supply 100 is connected to the vessel 14, thereby making the vessel
8 14 act as an anode. The negative lead 108 of the power supply 100 is
9 electrically connected to the contactor 20. Alternative embodiments may
10 use an anode (not shown) disposed inside the vessel 14. An arc initiator
11 102, at or near the electrical potential of the vessel 14, is used to initiate
12 the arc.

13 II. Operation of the Apparatus

14 Referring to FIG.1, in the operation of the present invention
15 cathodic arc coater 10, a plurality of substrates 12 and a cathode 18 are
16 attached to a platter 50 and the platter 50 is loaded into the vessel 14.
17 During loading, the platter center gear 64 engages the gear 68 disposed
18 within the vessel 14 and the biasing source 96 electrically connects with
19 the platter 50. At this point the substrates 12 have been degreased and
20 substantially cleaned, although each will likely have some molecular
21 contaminant and oxidation remaining on its exterior surface. The
22 actuating cylinders 92 subsequently actuate the contactor 20 into electrical
23 contact with the cathode 18 and the vessel 14 is closed.

24 The mechanical rough vacuum pump 34 is operated to evacuate the
25 vessel 14 to a predetermined pressure. Once that pressure is reached, the
26 high-volume diffusion vacuum pump 36 further evacuates the vessel 14 to
27 near vacuum conditions. The substrates 12 are then cleaned of any
28 remaining contaminants and/or oxidation by a method such as "sputter
29 cleaning". Sputter cleaning is a process well known in the art and will



1 not be described in detail here. Other cleaning methods may be used
2 alternatively. After the substrates 12 are cleaned, the contaminants are
3 purged typically using an inert gas.

4 Prior to initiating an arc several steps are completed, including: (1)
5 the substrates 12 are set to a particular bias via the biasing source 96,
6 making them electrically attractive to positive ions emitted from the
7 cathode 18; (2) the substrates 12 are placed in motion at a particular
8 rotational speed; (3) the power supply 100 is set to establish an arc having
9 a particular magnitude of current and voltage, but no arc is initiated; (4)
10 the vacuum pumps 34,36 establish and maintain a particular vacuum
11 pressure of gas within the vessel 14; and (5) coolant flows are established
12 through the cooling passages 30 attached to the vessel 14 and through the
13 cooling passages 32 within the contactor 20. Specific process parameters
14 will depend upon factors such as the substrate material, the material to be
15 coated, and the desired characteristics of the coating, etc.

16 Once the aforementioned steps have been completed, the arc
17 initiator 102 is brought into and out of contact with the evaporative
18 surface 42 of the cathode 18, causing an arc to jump between the arc
19 initiator 102 and the evaporative surface 42. The arc initiator 102 is
20 subsequently moved a distance away from the cathode 18, preferably
21 radially outside of the substrates 12. Once the arc initiator 102 is no
22 longer proximate the cathode 18, the arc jumps between the cathode 18
23 and the deflector shields 98 electrically connected to the vessel 14 (or the
24 vessel 14 if there are no deflector shields 98). The magnetic field
25 generator 90 positioned in the contactor 20 produces a magnetic field that
26 runs parallel to the evaporative surface 42 of the cathode 18 which drives
27 the arc along an arc path 104 around the evaporative surface 42 of the
28 cathode 18.

29 The energy delivered by the arc causes the material at the cathode
30 spot to vaporize, thereby liberating atoms, molecules, ions, electrons, and



1 particles from the cathode 18. FIG.4 shows an eroded cathode 18 in
2 phantom. The erosion is substantially symmetrical relative to the arc path
3 104. The biased substrates 12 attract the ions, causing them to accelerate
4 toward the substrates 12. The ions strike the exterior surface of the
5 substrates 12, attach and collectively form a coating of the cathode
6 material. The rotation of the substrates 12 relative to the cathode 18
7 promotes uniform deposition of the coating on the substrate 12. Coolant
8 passes through and directly cools the contactor 20, and indirectly cools the
9 cathode 18.

10 When a coating of sufficient thickness has been deposited on the
11 substrates 12, the power supply 100 is turned off and the arc extinguished.
12 The vessel 14 is purged with inert gas and brought to ambient pressure.
13 The contactor 20 is actuated out of contact with the cathode 18 and the
14 platter 50 is removed from the vessel 14. The substrates 12 (and cathode
15 18 if necessary) are subsequently removed and new substrates 12 (and
16 cathode 18) attached. The loaded platter 50 is then inserted back into the
17 vessel 14 in the manner described earlier and the process repeated.

18 Although this invention has been shown and described with respect
19 to the detailed embodiments thereof, it will be understood by those skilled
20 in the art that various changes in form and detail thereof may be made
21 without departing from the spirit and the scope of the invention. For
22 example, the means 76 for cooling the contactor 20 is described as having
23 a cooling tube 80 coaxially positioned within the contactor shaft 74.
24 Alternative means of delivering coolant to the head 72 of the contactor 20
25 may be used. Another alternative embodiment of the present invention
26 includes a second contactor (not shown) that actuates up through the
27 platter 50. The second contactor may also include means for cooling, for
28 improved cooling of the cathode.



We claim:

1. An apparatus for applying material by cathodic arc vapor deposition to a substrate, comprising:

a vessel;

means for maintaining a vacuum in said vessel;

a cathode, positioned inside said vessel;

a contactor, positioned inside said vessel;

means for selectively sustaining an arc of electrical energy between said cathode and an anode, wherein said means for sustaining an arc of electrical energy is electrically connected to said contactor; and

an actuator, wherein said actuator selectively actuates said contactor into electrical contact with said cathode, and thereby electrically connects said cathode to said means for sustaining an arc of electrical energy;

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 inside said vessel.

2. An apparatus according to claim 1, wherein said means for selectively 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 contactor, and said positive lead is electrically connected to said vessel, thereby making said vessel, and any member electrically connected to said vessel, act as said anode; and

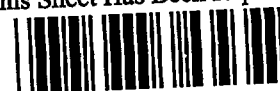
wherein said cathode is electrically insulated from said vessel.

3. An apparatus according to claim 1, wherein said contactor comprises:

{F-7863}



THIS SHEET HAS BEEN
REPLACED



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

1 4. An apparatus according to claim 3, wherein said contactor further
2 comprises means for cooling said contactor.

1 5. An apparatus according to claim 4, wherein said cooling means
2 comprises:

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

1 6. An apparatus according to claim 4, wherein said cathode is disk-
2 shaped having a pair of end surfaces connected by an evaporative surface,
3 wherein said actuator actuates said contactor into contact with one of said
4 end surfaces of said cathode.

1 7. An apparatus according to claim 6, further comprising:
2 a platter, for holding the substrates and said cathode;
3 wherein said cathode is electrically insulated from said platter; and
4 wherein said platter may be selectively removed from said vessel.

1 8. An apparatus according to claim 7, wherein said platter further
2 comprises:
3 a plurality of pedestals, pivotly attached to said platter, wherein the
4 substrates are attached to said pedestals.





1 9. An apparatus according to claim 8, wherein said platter further
2 comprises means for rotating said pedestals, wherein rotating said
3 pedestals and the attached substrates, changes the orientation of the
4 substrates relative to said cathode.

1 10. An apparatus according to claim 9, wherein said means for rotating
2 said pedestals comprises:

3 a center gear, pivotly attached to said platter;

4 a plurality of pedestal gears, each fixed to one of said pedestals
5 and pivotly attached to said platter, and each said pedestal gear engaged
6 with said center gear;

7 wherein said rotating said center gear causes said pedestal gears to
8 rotate.

1 11. An apparatus according to claim 10, further comprising:

2 a drive gear, disposed inside said vessel, said drive gear attached
3 to a shaft which extends outside said vessel;

4 wherein said drive gear is selectively engagable with said center
5 gear;

6 wherein rotating said drive gear, when engaged with said center
7 gear, causes said center gear and pedestal gears to rotate.

1 12. An apparatus according to claim 11, wherein said means for
2 selectively sustaining an arc of electrical energy between said cathode and
3 said anode comprises:

4 a power supply, having a negative lead electrically connected to
5 said contactor, and a positive lead electrically connected to said vessel,
6 thereby making said vessel and any member electrically connected to said
7 vessel, act as said anode; and

8 wherein said cathode is electrically insulated from said vessel.

{F-7863}

13



* C L M S *

THIS SHEET HAS BEEN
REPLACED



1 13. An apparatus according to claim 7, further comprising:
2 a biasing source, for electrically biasing the substrates;
3 means for electrically connecting said biasing source to the
4 substrates.

1 14. An apparatus according to claim 13, wherein said means for
2 electrically connecting said biasing source to the substrates electrically
3 connects said biasing source to said platter, and said platter is electrically
4 connected to the substrates.

1 15. An apparatus according to claim 7, further comprising:
2 a plurality of spacers;
3 an insulator pad, disposed between said spacers, said insulator pad
4 electrically insulating said spacers from one another;
5 wherein said spacers and said pad are disposed between said
6 cathode and said platter, thereby electrically insulating said cathode from
7 said platter.

1 16. An apparatus according to claim 1, wherein said cathode is disk-
2 shaped having a pair of end surfaces connected by an evaporative surface;
3 wherein said actuator actuates said contactor into contact with one
4 of said end surfaces of said cathode, thereby electrically connecting said
5 cathode to said means for selectively sustaining an arc of electrical energy
6 between said cathode and said anode.

1 17. An apparatus according to claim 16, wherein said contactor
2 comprises:
3 a head, positioned inside said vessel; and
4 a shaft, having a bore, attached to said head, said shaft extending
5 from said head to outside said vessel.

{F-7863}

14



THIS SHEET HAS BEEN
REPLACED



1 18. An apparatus according to claim 17, wherein said contactor further
2 comprises means for cooling said contactor.

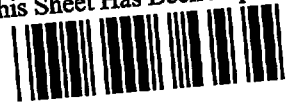
1 19. An apparatus according to claim 18, wherein said cooling means
2 comprises:

3 a cooling tube, positioned inside said bore of said contactor shaft,
4 wherein a passage is formed between said cooling tube and said shaft;

5 a coolant supply, connected to said cooling tube and said passage,
6 for providing a coolant within said contactor.

1 20. An apparatus according to claim 1, wherein said actuator
2 comprises a selectively actuating cylinder connected to said contactor shaft
3 outside said vessel, wherein said actuating cylinder selectively actuates
4 said contactor into electrical contact with said cathode by moving said
5 contactor into and out of physical contact with said cathode.





ABSTRACT OF THE DISCLOSURE

An apparatus for applying material by cathodic arc deposition to a substrate is provided which includes a vessel, means for maintaining a vacuum in the vessel, a cathode, a contactor, means for selectively sustaining an arc of electrical energy between the cathode and an anode, and an actuator. The cathode and contactor are positioned inside the vessel, and the contactor is electrically connected to the means for selectively sustaining an arc of electrical energy. The actuator selectively actuates the contactor into electrical contact with the cathode, and thereby electrically connects the cathode to the means for sustaining an arc of electrical energy.

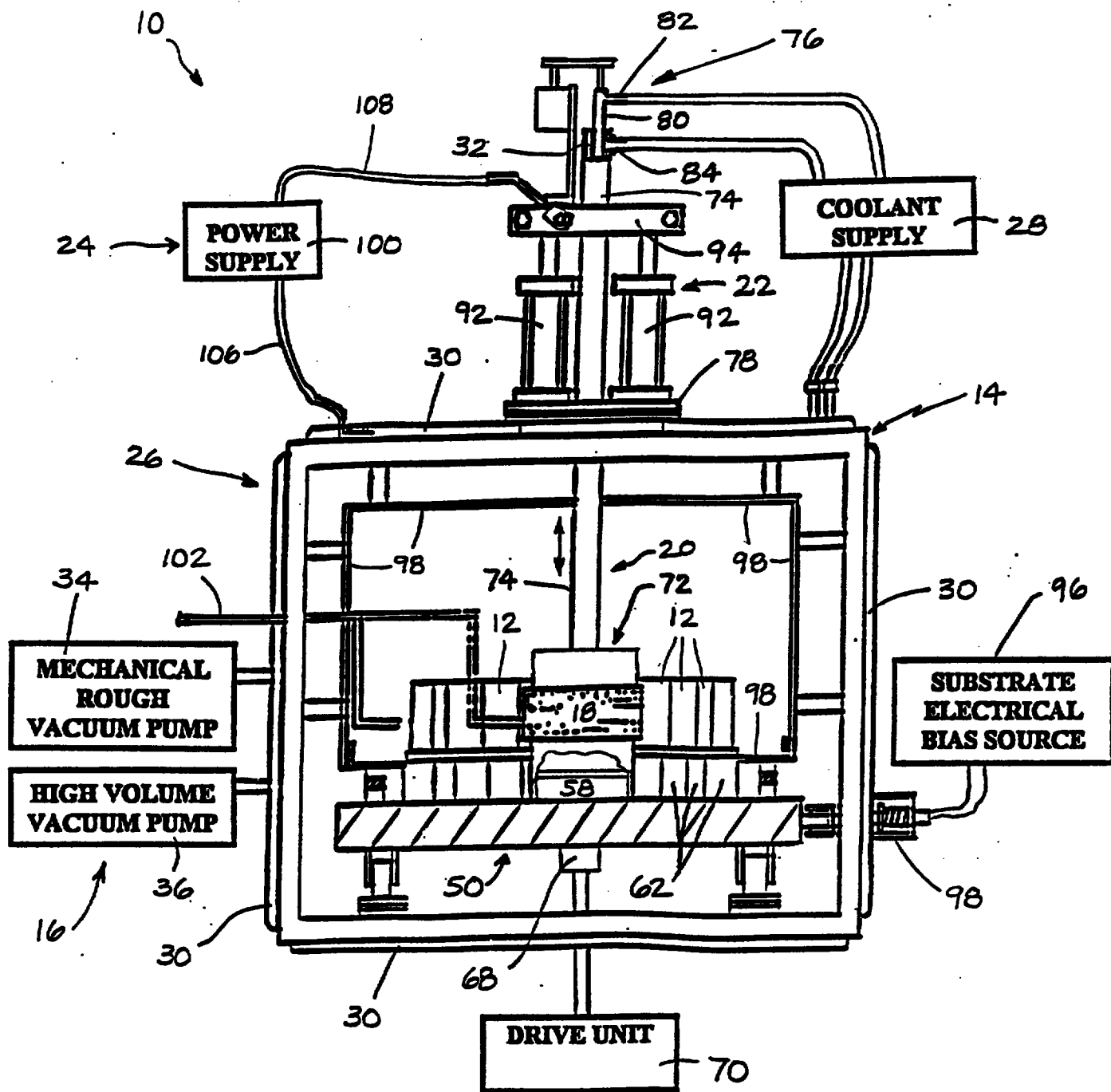
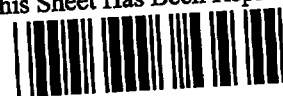


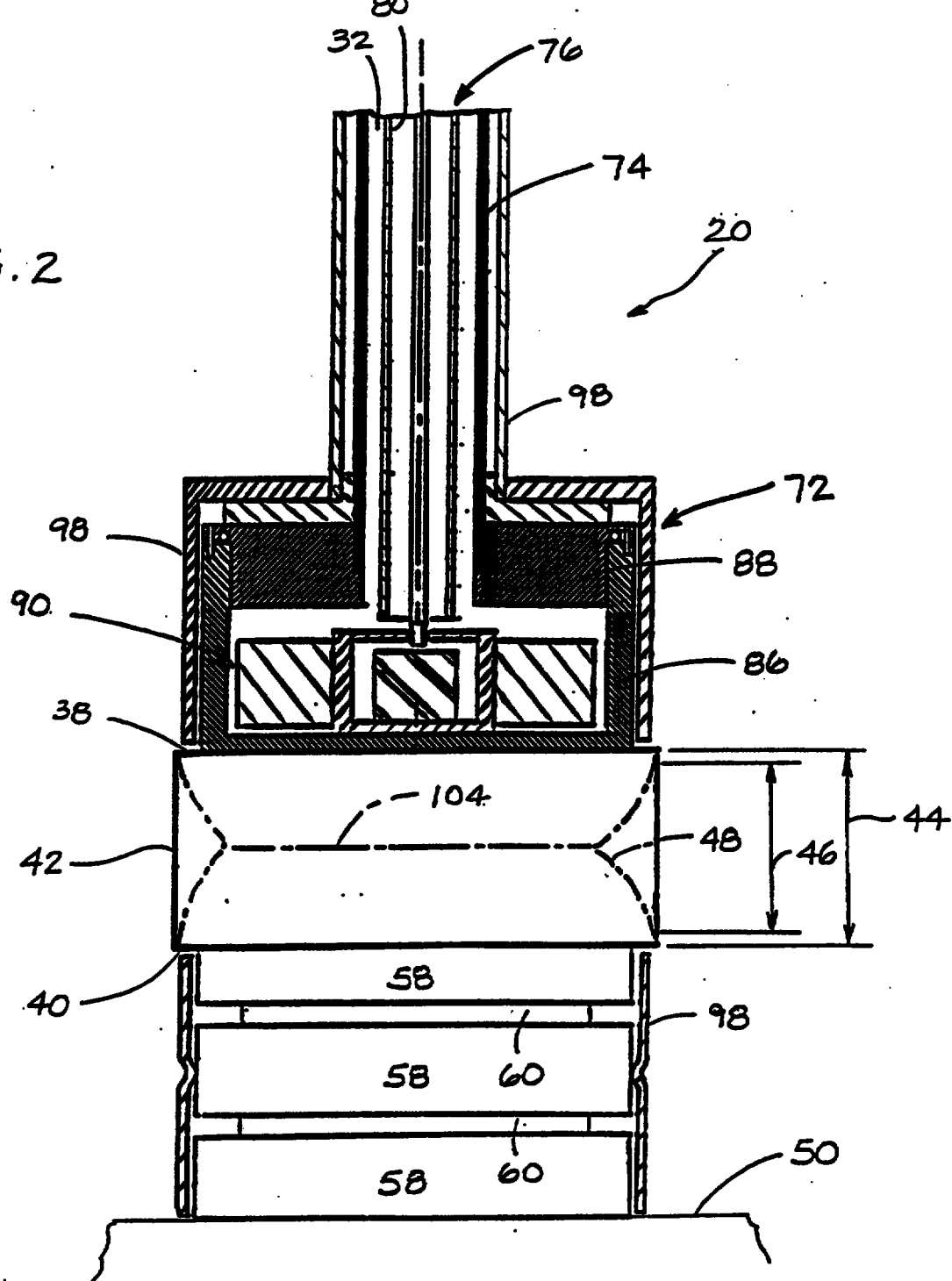
FIG. 1

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

FIG. 2



This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

FIG. 3

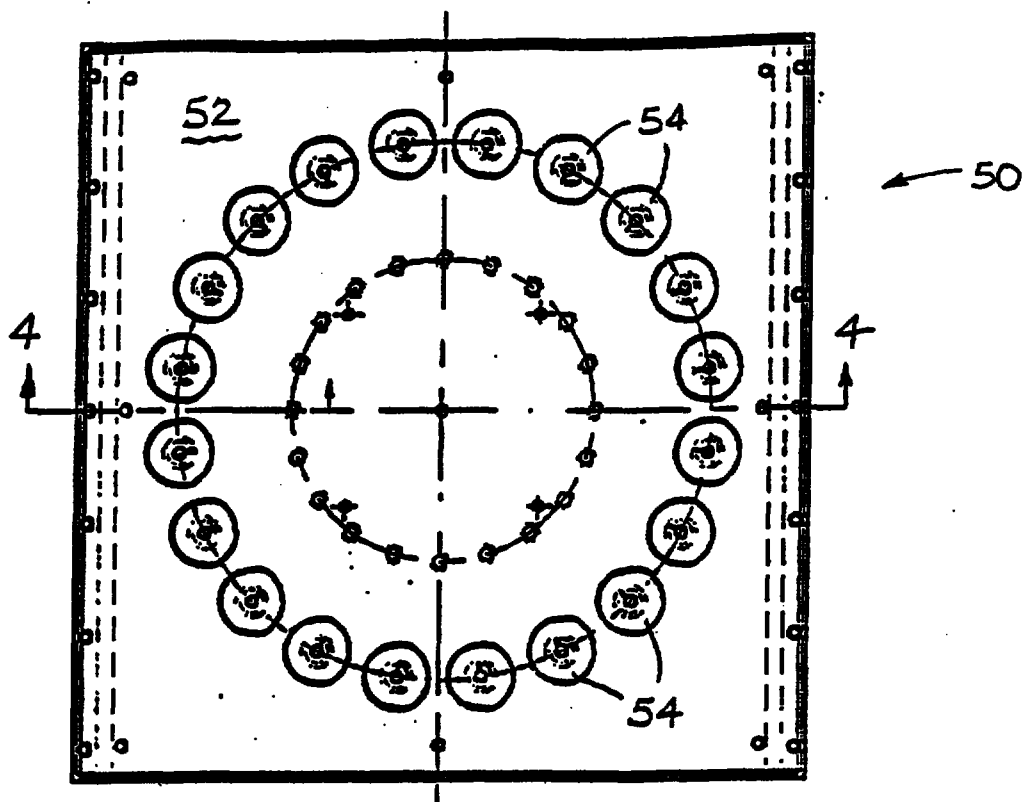
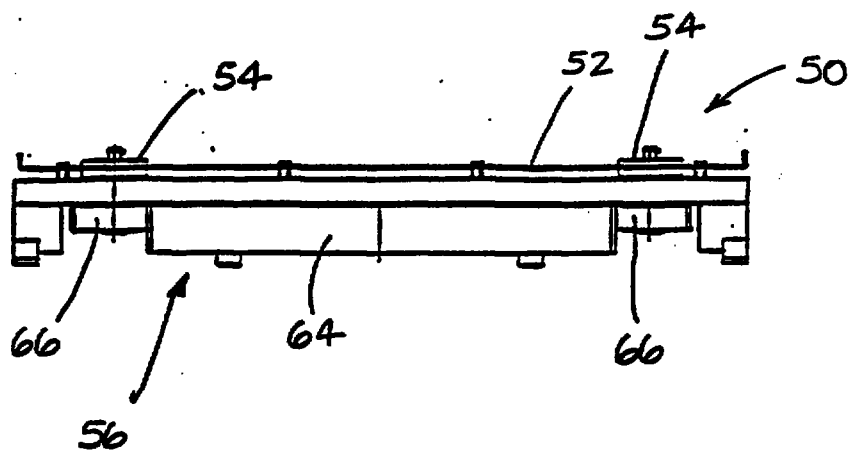


FIG. 4



This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

30 NOV 1998

Cathodic Arc Vapor Deposition Apparatus

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. An arc-initiating trigger, at or near the same potential as the anode, contacts and moves away from the cathode. When the trigger is 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 is referred to as a cathode spot. Absent a steering

1 mechanism, a cathode spot will move randomly about the surface of the
2 cathode.

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

20 Presently available cathodic arc coaters typically use a cooled
21 cathode fixed in place within the coater. One cooling scheme provides a
22 manifold attached to the cathode that permits the passage of coolant
23 between the cathode and manifold. Another scheme uses coolant piping
24 connected to a hollow cathode. A problem with either scheme is that the
25 cathode must be machined to accept the manifold or piping. Not all
26 cathode materials are amenable to machining and even where possible,
27 machining adds significantly to the cost of the consumable cathode.
28 Another problem with directly cooling the cathode is the labor required
29 to replace the cathode when its useful life has expired. In the previous
30 example where a manifold (or piping) is mechanically attached to the

30 NOV 1998

1 cathode, the manifold (or piping) must be detached from the old cathode
2 and attached to a new one, and the deposition chamber subsequently
3 cleaned of coolant. For those applications which require cathode
4 replacement after each coating run, the labor costs and down time can be
5 considerable. Still another problem with direct cathode cooling is
6 leakage. Coolant leakage occurring during deposition can contaminate the
7 substrates being coated and require extensive cleaning within the
8 deposition chamber. Airfoils for gas turbine engines are an example of
9 an expensive substrate to be coated; one where it would be a distinct
10 advantage to minimize or eliminate losses due to contamination.

11 In short, what is needed is an apparatus for cathodic arc vapor
12 deposition of material on a substrate that operates efficiently, one capable
13 of repeatably providing a high quality coatings on a substrate, and one
14 that operates cost effectively.

15 DISCLOSURE OF THE INVENTION

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

19 It is another object of the present invention to provide an apparatus
20 for cathodic arc vapor deposition of material on a substrate that repeatably
21 provides a high quality coating on a substrate.

22 According to the present invention, an apparatus for applying
23 material by cathodic arc vapor deposition to a substrate is provided which
24 includes a vessel, means for maintaining a vacuum in the vessel, a
25 cathode, a contactor, means for selectively sustaining an arc of electrical
26 energy between the cathode and an anode, and an actuator. The cathode
27 and contactor are positioned inside the vessel, and the contactor is
28 electrically connected to the means for selectively sustaining an arc of
29 electrical energy. The actuator selectively actuates the contactor into

30 NOV 1998

1 electrical contact with the cathode, and thereby electrically connects the
2 cathode to the means for sustaining an arc of electrical energy. The arc
3 of electrical energy extending between the cathode and the anode liberates
4 cathode material, which is subsequently deposited on the substrate located
5 inside the vessel.

6 An advantage of the present invention is that the present invention
7 apparatus for cathodic arc vapor deposition of material on a substrate is
8 designed to operate in a cost effective manner. One cost effective
9 characteristic of the present invention is the cathode. The present
10 invention cathode is preferably disk-shaped and can be cut, for example,
11 from a cylindrical casting. The simply formed cathode requires minimal
12 expensive machining, thereby reducing the cost of the cathode and the
13 overall coating process. Another cost effective characteristic is that the
14 cathode is indirectly cooled. Presently available cathodic arc coaters that
15 pass coolant in direct contact with the cathode (i.e., direct cooling)
16 generally require machining to accept a manifold or piping. The
17 machining significantly increases the cost of the consumable cathode.
18 Another cost effective characteristic is that the cathode is readily inserted
19 in the vessel. Some prior art cathodic arc coaters have cathodes that are
20 fastened in place with the deposition chamber, and/or have attached
21 cooling apparatus. In either case, the labor to install and remove the
22 cathode undesirably increases the cost of the coating process. Another
23 cost effective characteristic of the present invention is that the form of the
24 used cathode facilitates recycling. The used cathode is made of high
25 quality material that has been exposed to few, if any, contaminants.
26 Consequently, the cathodes have considerable scrap value that reduces the
27 cost of the coating process.

28 Another advantage of the present invention is that high quality
29 coatings can be consistently produced. The platter provides for rotation
30 of the substrates to promote uniform deposition, and the indirect cooling

30 NOV 1998

1 of the cathode via the contactor minimizes the chance of coolant
2 contamination. Hence, high quality coatings can be consistently deposited
3 on substrates.

4 These and other objects, features and advantages of the present
5 invention will become apparent in light of the detailed description of the
6 best mode embodiment thereof, as illustrated in the accompanying
7 drawings.

8 BRIEF DESCRIPTION OF THE DRAWINGS

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

11 FIG.2 is a top diagrammatic view of the present invention platter.

12 FIG.3 is a side view of the platter shown in FIG.2.

13 FIG. 4 is a diagrammatic cross-sectional view of a contactor.

14 BEST MODE FOR CARRYING OUT THE INVENTION

15 I. Apparatus

16 Referring to FIG.1, an apparatus 10 for cathodic arc vapor
17 deposition on a substrate 12, hereinafter referred to as a "cathodic arc
18 coater", is provided having a vessel 14, means 16 for maintaining a
19 vacuum in the vessel 14, a cathode 18, a contactor 20, an actuator 22 for
20 selectively actuating the contactor 20 into electrical contact with the
21 cathode 18, and means 24 for sustaining an arc of electrical energy
22 between the cathode 18 and an anode 26. A coolant supply 28 maintains
23 the coater 10 within acceptable temperatures by cycling coolant through
24 passages 30,32 within the vessel 14 and contactor 20, respectively. In the
25 preferred embodiment, the means 16 for maintaining a vacuum in the
26 vessel 14 includes a mechanical rough vacuum pump 34 and a high-
27 volume diffusion-type vacuum pump 36 piped to the interior of the vessel
28 14. Other vacuum means may be used alternatively.

30 NOV 1998

1 Referring to FIG.2, the cathode 18 is a substantially cylindrical
2 disk having a first end surface 38, a second end surface 40, and an
3 evaporative surface 42 extending therebetween. The end surfaces 38,40
4 are substantially parallel with one another. The material composition of
5 the cathode 18 will depend upon the material to be deposited, and in most
6 cases the cathode 18 can be cut from a cast rod. The axial length 44 of
7 the evaporative surface 42 is preferably longer than the anticipated final
8 axial length 46 of the erosion pattern 48 along the evaporative surface 42.
9 Keeping the erosion pattern 48 between the end surfaces 38,40 minimizes
10 the possibility that the arc will leave the evaporative surface 42 of the
11 cathode 18.

12 Referring to FIGS. 1, 3 and 4, in the preferred embodiment the
13 cathode 18 is positioned on a removable platter 50. The platter 50
14 includes a tray 52, a plurality of pedestals 54, and means 56 for rotating
15 the pedestals 54. The cathode 18 is mounted in the center of the platter
16 50, on top of a plurality of spacers 58 (see also FIG.2) separated by
17 electrical insulators 60. Adapters 62 attached to the pedestals 54 can be
18 used to align the substrates 12 radially outside the cathode 18.

19 The means 56 for rotating the pedestals 54 includes a center gear
20 64 engaged with a plurality of pedestal gears 66. Each pedestal gear 66
21 is fixed to a pedestal 54, and the center and pedestal gears 64,66 are
22 pivotly attached to the tray 52. The center gear 64 is driven by a gear 68
23 positioned inside the vessel 14. A shaft extending through the vessel wall
24 connects the gear 68 to a drive unit 70.

25 Referring to FIGS. 1 and 2, the contactor 20 includes a head 72
26 attached to a shaft 74, and means 76 for cooling the contactor 20. The
27 head 72 is positioned inside the vessel 14 and the shaft 74 extends from
28 the head 72 to outside the vessel 14. An insulative disk 78 (FIG.1)
29 electrically insulates the contactor 20 from the vessel 14. The means 76
30 for cooling the contactor 20 includes a cooling tube 80 coaxially

30 NOV 1998

1 positioned within the shaft 74, a coolant inlet port 82 connected to the
2 cooling tube 80, and a coolant exit port 84 connected to the passage 32
3 formed between the coaxial coolant tube 80 and shaft 74. The coaxial
4 arrangement between the cooling tube 80 and the shaft 74 allows coolant
5 to flow in the cooling tube 80 and exit via the passage 32 between the
6 shaft 74 and the cooling tube 80, or vice versa. The head 72 includes a
7 cup 86 and a shaft flange 88. The shaft flange 88 is fixed to the shaft 74
8 and the cup 86 is fixed to the shaft flange 88. The cup 86, shaft flange
9 88, and shaft 74 are fabricated from an electrically conductive material
10 such as a copper alloy. The preferred embodiment of the head 72 further
11 includes a magnetic field generator 90.

12 Referring to FIG.1, the actuator 22 for selectively actuating the
13 contactor 20 into electrical contact with the cathode 18 includes a pair of
14 two-way actuating cylinders 92 (hydraulic or pneumatic) for acting
15 between the vessel 14 and a shaft flange 94 attached to the contactor shaft
16 74. Mechanical apparatus (not shown) may be used in place of the
17 actuating cylinders 92. A commercially available controller can be used
18 to control the position and force of the cylinders (or mechanical
19 apparatus).

20 In the preferred embodiment, the cathodic arc coater 10 includes
21 a biasing source 96 for electrically biasing the substrates 12. A contact-
22 type switch 98 electrically connects the biasing source 96 and the platter
23 50. The substrates 12, which are mechanically and electrically attached
24 to the platter 50, are consequently electrically connected to the biasing
25 source 96. Other means for electrically connecting the substrates 12 to
26 the biasing source 96 may be used alternatively.

27 Deflector shields 98 are used throughout the cathodic arc coater 10
28 to confine the vaporized cathode materials in the area of the substrates 12.
29 The shields 98 attached to the vessel 14, platter 50, spacers 58, and
30 contactor 20 help minimize undesirable material build-up on those

30 NOV 1998

1 surfaces. In the preferred embodiment, the deflector shields 98 attached
2 to the vessel 14 are electrically connected to the vessel 14 and are made
3 of an electrically conductive material such as stainless steel.

4 The means 24 for sustaining an arc of electrical energy between
5 the cathode 18 and an anode 26 includes a direct current (D.C.) power
6 supply 100. In the preferred embodiment, the positive lead 106 of the
7 power supply 100 is connected to the vessel 14, thereby making the vessel
8 14 act as an anode. The negative lead 108 of the power supply 100 is
9 electrically connected to the contactor 20. Alternative embodiments may
10 use an anode (not shown) disposed inside the vessel 14. An arc initiator
11 102, at or near the electrical potential of the vessel 14, is used to initiate
12 the arc.

13 II. Operation of the Apparatus

14 Referring to FIG.1, in the operation of the present invention
15 cathodic arc coater 10, a plurality of substrates 12 and a cathode 18 are
16 attached to a platter 50 and the platter 50 is loaded into the vessel 14.
17 During loading, the platter center gear 64 engages the gear 68 disposed
18 within the vessel 14 and the biasing source 96 electrically connects with
19 the platter 50. At this point the substrates 12 have been degreased and
20 substantially cleaned, although each will likely have some molecular
21 contaminant and oxidation remaining on its exterior surface. The
22 actuating cylinders 92 subsequently actuate the contactor 20 into electrical
23 contact with the cathode 18 and the vessel 14 is closed.

24 The mechanical rough vacuum pump 34 is operated to evacuate the
25 vessel 14 to a predetermined pressure. Once that pressure is reached, the
26 high-volume diffusion vacuum pump 36 further evacuates the vessel 14 to
27 near vacuum conditions. The substrates 12 are then cleaned of any
28 remaining contaminants and/or oxidation by a method such as "sputter
29 cleaning". Sputter cleaning is a process well known in the art and will

30 NOV 1998

1 not be described in detail here. Other cleaning methods may be used
2 alternatively. After the substrates 12 are cleaned, the contaminants are
3 purged typically using an inert gas.

4 Prior to initiating an arc several steps are completed, including: (1)
5 the substrates 12 are set to a particular bias via the biasing source 96,
6 making them electrically attractive to positive ions emitted from the
7 cathode 18; (2) the substrates 12 are placed in motion at a particular
8 rotational speed; (3) the power supply 100 is set to establish an arc having
9 a particular magnitude of current and voltage, but no arc is initiated; (4)
10 the vacuum pumps 34,36 establish and maintain a particular vacuum
11 pressure of gas within the vessel 14; and (5) coolant flows are established
12 through the cooling passages 30 attached to the vessel 14 and through the
13 cooling passages 32 within the contactor 20. Specific process parameters
14 will depend upon factors such as the substrate material, the material to be
15 coated, and the desired characteristics of the coating, etc.

16 Once the aforementioned steps have been completed, the arc
17 initiator 102 is brought into and out of contact with the evaporative
18 surface 42 of the cathode 18, causing an arc to jump between the arc
19 initiator 102 and the evaporative surface 42. The arc initiator 102 is
20 subsequently moved a distance away from the cathode 18, preferably
21 radially outside of the substrates 12. Once the arc initiator 102 is no
22 longer proximate the cathode 18, the arc jumps between the cathode 18
23 and the deflector shields 98 electrically connected to the vessel 14 (or the
24 vessel 14 if there are no deflector shields 98). The magnetic field
25 generator 90 positioned in the contactor 20 produces a magnetic field that
26 runs parallel to the evaporative surface 42 of the cathode 18 which drives
27 the arc along an arc path 104 around the evaporative surface 42 of the
28 cathode 18.

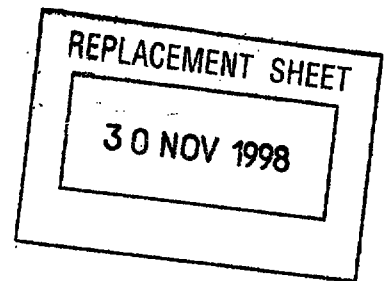
29 The energy delivered by the arc causes the material at the cathode
30 spot to vaporize, thereby liberating atoms, molecules, ions, electrons, and

30 NOV 1998

1 particles from the cathode 18. FIG.4 shows an eroded cathode 18 in
2 phantom. The erosion is substantially symmetrical relative to the arc path
3 104. The biased substrates 12 attract the ions, causing them to accelerate
4 toward the substrates 12. The ions strike the exterior surface of the
5 substrates 12, attach and collectively form a coating of the cathode
6 material. The rotation of the substrates 12 relative to the cathode 18
7 promotes uniform deposition of the coating on the substrate 12. Coolant
8 passes through and directly cools the contactor 20, and indirectly cools the
9 cathode 18.

10 When a coating of sufficient thickness has been deposited on the
11 substrates 12, the power supply 100 is turned off and the arc extinguished.
12 The vessel 14 is purged with inert gas and brought to ambient pressure.
13 The contactor 20 is actuated out of contact with the cathode 18 and the
14 platter 50 is removed from the vessel 14. The substrates 12 (and cathode
15 18 if necessary) are subsequently removed and new substrates 12 (and
16 cathode 18) attached. The loaded platter 50 is then inserted back into the
17 vessel 14 in the manner described earlier and the process repeated.

18 Although this invention has been shown and described with respect
19 to the detailed embodiments thereof, it will be understood by those skilled
20 in the art that various changes in form and detail thereof may be made
21 without departing from the spirit and the scope of the invention. For
22 example, the means 76 for cooling the contactor 20 is described as having
23 a cooling tube 80 coaxially positioned within the contactor shaft 74.
24 Alternative means of delivering coolant to the head 72 of the contactor 20
25 may be used. Another alternative embodiment of the present invention
26 includes a second contactor (not shown) that actuates up through the
27 platter 50. The second contactor may also include means for cooling, for
28 improved cooling of the cathode.



We claim:

1. An apparatus for applying material by cathodic arc vapor deposition to a substrate, comprising:

a vessel;

means for maintaining a vacuum in said vessel;

a cathode, positioned inside said vessel;

a contactor, positioned inside said vessel;

means for selectively sustaining an arc of electrical energy between said cathode and an anode, wherein said means for sustaining an arc of electrical energy is electrically connected to said contactor; and

an actuator, wherein said actuator selectively actuates said contactor into electrical contact with said cathode, and thereby electrically connects said cathode to said means for sustaining an arc of electrical energy;

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 inside said vessel.

2. An apparatus according to claim 1, wherein said means for selectively sustaining an arc of electrical energy between said cathode and said anode comprises:

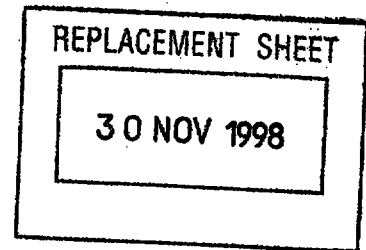
a power supply, having a positive lead and a negative lead;

wherein said negative lead of said power supply is electrically connected to said contactor, and said positive lead is electrically connected to said vessel, thereby making said vessel, and any member electrically connected to said vessel, act as said anode; and

wherein said cathode is electrically insulated from said vessel.

3. An apparatus according to claim 1, wherein said contactor comprises:





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

1 4. An apparatus according to claim 3, wherein said contactor further
2 comprises means for cooling said contactor.

1 5. An apparatus according to claim 4, wherein said cooling means
2 comprises:

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

1 6. An apparatus according to claim 4, wherein said cathode is disk-
2 shaped having a pair of end surfaces connected by an evaporative surface,
3 wherein said actuator actuates said contactor into contact with one of said
4 end surfaces of said cathode.

1 7. An apparatus according to claim 6, further comprising:
2 a platter, for holding the substrates and said cathode;
3 wherein said cathode is electrically insulated from said platter; and
4 wherein said platter may be selectively removed from said vessel.

1 8. An apparatus according to claim 7, wherein said platter further
2 comprises:

3 a plurality of pedestals, pivotly attached to said platter, wherein the
4 substrates are attached to said pedestals.



30 NOV 1998

1 9. An apparatus according to claim 8, wherein said platter further
2 comprises means for rotating said pedestals, wherein rotating said
3 pedestals and the attached substrates, changes the orientation of the
4 substrates relative to said cathode.

1 10. An apparatus according to claim 9, wherein said means for rotating
2 said pedestals comprises:

3 a center gear, pivotly attached to said platter;

4 a plurality of pedestal gears, each fixed to one of said pedestals
5 and pivotly attached to said platter, and each said pedestal gear engaged
6 with said center gear;

7 wherein said rotating said center gear causes said pedestal gears to
8 rotate.

1 11. An apparatus according to claim 10, further comprising:

2 a drive gear, disposed inside said vessel, said drive gear attached
3 to a shaft which extends outside said vessel;

4 wherein said drive gear is selectively engagable with said center
5 gear;

6 wherein rotating said drive gear, when engaged with said center
7 gear, causes said center gear and pedestal gears to rotate.

1 12. An apparatus according to claim 11, wherein said means for
2 selectively sustaining an arc of electrical energy between said cathode and
3 said anode comprises:

4 a power supply, having a negative lead electrically connected to
5 said contactor, and a positive lead electrically connected to said vessel,
6 thereby making said vessel and any member electrically connected to said
7 vessel, act as said anode; and

8 wherein said cathode is electrically insulated from said vessel.



30 NOV 1998

1 13. An apparatus according to claim 7, further comprising:
2 a biasing source, for electrically biasing the substrates;
3 means for electrically connecting said biasing source to the
4 substrates.

1 14. An apparatus according to claim 13, wherein said means for
2 electrically connecting said biasing source to the substrates electrically
3 connects said biasing source to said platter, and said platter is electrically
4 connected to the substrates.

1 15. An apparatus according to claim 7, further comprising:
2 a plurality of spacers;
3 an insulator pad, disposed between said spacers, said insulator pad
4 electrically insulating said spacers from one another;
5 wherein said spacers and said pad are disposed between said
6 cathode and said platter, thereby electrically insulating said cathode from
7 said platter.

1 16. An apparatus according to claim 1, wherein said cathode is disk-
2 shaped having a pair of end surfaces connected by an evaporative surface;
3 wherein said actuator actuates said contactor into contact with one
4 of said end surfaces of said cathode, thereby electrically connecting said
5 cathode to said means for selectively sustaining an arc of electrical energy
6 between said cathode and said anode.

1 17. An apparatus according to claim 16, wherein said contactor
2 comprises:
3 a head, positioned inside said vessel; and
4 a shaft, having a bore, attached to said head, said shaft extending
5 from said head to outside said vessel.



30 NOV 1998

1 18. An apparatus according to claim 17, wherein said contactor further
2 comprises means for cooling said contactor.

1 19. An apparatus according to claim 18, wherein said cooling means
2 comprises:

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

1 20. An apparatus according to claim 1, wherein said actuator
2 comprises a selectively actuating cylinder connected to said contactor shaft
3 outside said vessel, wherein said actuating cylinder selectively actuates
4 said contactor into electrical contact with said cathode by moving said
5 contactor into and out of physical contact with said cathode.



THIS SHEET HAS BEEN
REPLACED

REPLACEMENT SHEET

30 NOV 1998

Cathodic Arc Vapor Deposition Apparatus

ABSTRACT OF THE DISCLOSURE

1
2
3
4
5
6
7
8
9
10
11

An apparatus for applying material by cathodic arc deposition to a substrate is provided which includes a vessel, means for maintaining a vacuum in the vessel, a cathode, a contactor, means for selectively sustaining an arc of electrical energy between the cathode and an anode, and an actuator. The cathode and contactor are positioned inside the vessel, and the contactor is electrically connected to the means for selectively sustaining an arc of electrical energy. The actuator selectively actuates the contactor into electrical contact with the cathode, and thereby electrically connects the cathode to the means for sustaining an arc of electrical energy.

(Figure 1)

This Sheet Has Been Replaced

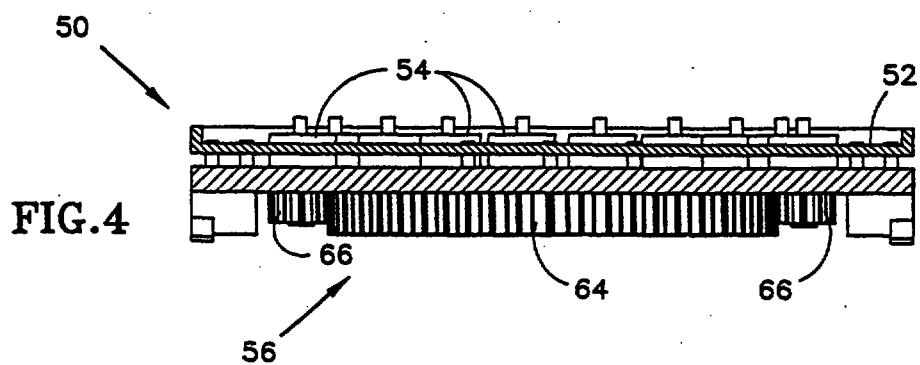
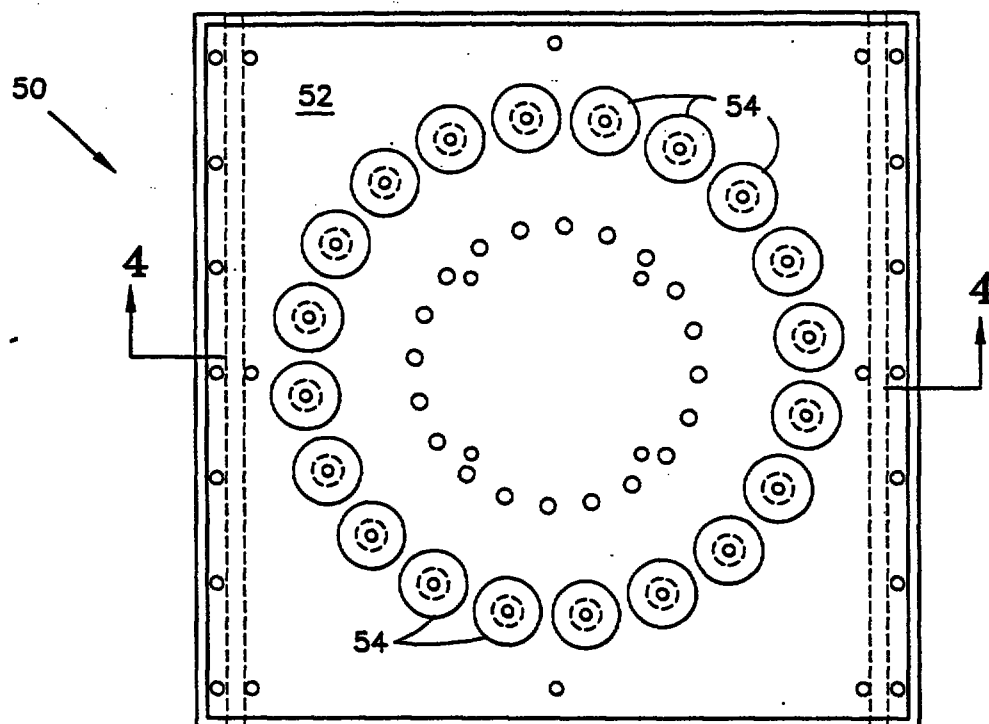


This diagram shows a cross-sectional view of a device assembly. At the top, a central vertical structure (76) is surrounded by a sleeve (80) and a flange (32). Below this, a horizontal section (72) contains a central core (88) and a surrounding layer (86). The entire assembly is supported by a base (50) which includes a central column (40) and a flange (42). The base is composed of several layers (58) and a bottom plate (60). Dimensions 44, 46, and 48 are indicated for the vertical sections of the base. Other labels include 20, 74, 98, 80, 32, 76, 88, 86, 90, 38, 104, 58, 60, and 50.

30 NOV 1998

3

FIG.3





TEXT OF THE ABSTRACT

CATHODIC ARC VAPOR DEPOSITION APPARATUS

An apparatus (10) for applying material by cathodic arc deposition to a substrate (12) is provided which includes a vessel (14), means (16) for maintaining a vacuum in the vessel (14), a cathode (18), a contactor (20), means (24) for selectively sustaining an arc of electrical energy between the cathode (18) and an anode (26), and an actuator (22). The cathode and contactor are positioned inside the vessel, and the contactor is electrically connected to the means for selectively sustaining an arc of electrical energy. The actuator selectively actuates the contactor into electrical contact with the cathode, and thereby electrically connects the cathode to the means of sustaining an arc of electrical energy.

Figure 1.

REPLACEMENT SHEET

16 JUL 1999