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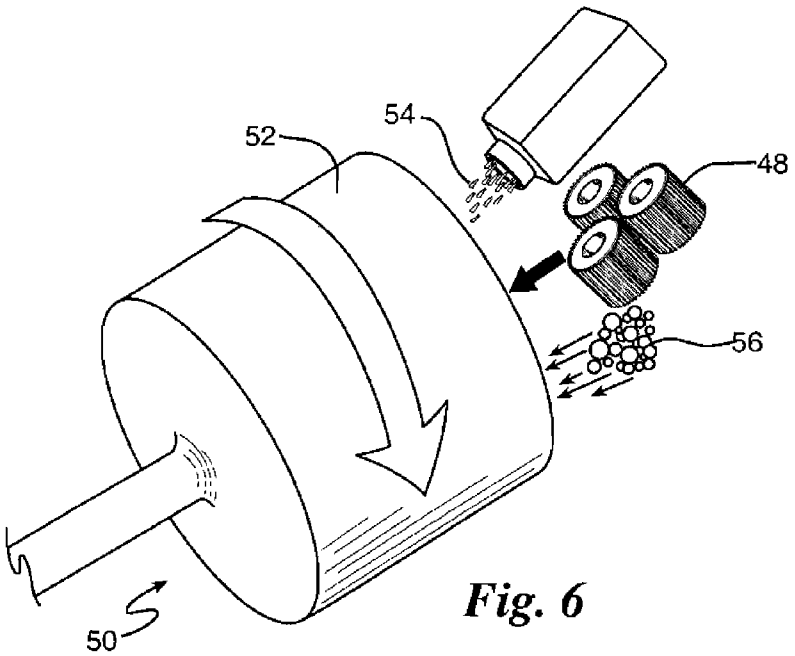


Fig. 6

(57) Abstract: A method and class of bond coat is provided herein that physically and chemically bonds solid layer lubricants and other functional coatings to a substrate by burnishing, for example, selected soft materials, including oxides such as antimony trioxide which is seen as a major improvement over conventional bonding or coating methods. The process is non-vacuum at ambient temperatures, no binders, adhesives, curing or baking. Lubricant performance can be enhanced by orders of magnitude compared to when the bond coat and burnishing process are not applied. The method is inexpensive, environmentally friendly, applicable to any substrate material, and scalable.

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LAYERS DURABLY BONDED TO SURFACES

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein can be manufactured and used by or for the U.S. Government for governmental purposes without the payment of any royalty thereon.

RELATED APPLICATIONS

[0002] None

FIELD OF THE INVENTION

[0003] This invention relates to methods for durable binding of a layer to a surface including a functional layer and the layered product so prepared.

BACKGROUND OF THE INVENTION

[0004] Friction is the resistance of one solid sliding over another solid; often the higher the friction the greater the wear of materials. The best way to reduce friction and wear is by separating the surfaces; this can be accomplished by the use of a liquid lubricant such as oil. The ideal condition is known as hydrodynamic lubrication and can eliminate wear by fully separating materials by a fluid film. Ideal conditions of hydrodynamic lubrication are rarely maintained in practice. Starting, stopping, misalignment, heavy loads and other conditions can cause the fluid film to be squeezed out, or allow surface asperities to break through the lubricant film, so that the two solids are pressed into contact with one another. Ideal hydrodynamic lubrication ends, and elastohydrodynamic or boundary lubrication begins. If no liquid is present the surface is either self lubricated (no lubrication) or a solid lubricant can be used. Solid film lubrication is a critical enabling technology employed in the absence of liquid lubricants. The choice to forgo a liquid lubricant or grease can be either by design constraints or by operating conditions being too severe for liquid and grease survival. Extreme operating conditions are typically defined by severe environments (e.g., water, chemicals), temperatures, and pressures. Extreme operating conditions require a distinct and separate class of lubricants. The harsh environment of outer space or internal combustion engines is marked by such extreme conditions and has spurred the development of a special class of lubricants

which are not organic based. The extreme operating conditions found in space sometimes preclude the use of conventional liquids and greases. Solid film lubricants have been very successful in fulfilling the role of providing wear protection in such conditions. Relative to liquid lubricants, solid lubricants generally have lower vapor pressures, better boundary lubrication properties and relative insensitivity to radiation effects, and operate in wider temperature ranges.

[0005] Successful solid film lubricants are characterized by the following properties:

- low shear strength
- high adhesion
- low abrasivity
- thermo-dynamic stability.

[0006] For moving mechanical components these properties are essential to reduce metal on metal contact and thereby reduce friction, heat, and wear. Much work has been done in identifying materials which have the above properties. Generally, but not exclusively, there are 3 distinct classes of soft solid film lubes meeting these criteria:

- Graphite (DLC, although carbon based, is not a soft solid film)
- Dichalcogenides of molybdenum and tungsten
- Soft Metals

Graphite

[0007] Graphite is the stable form of carbon. The bulk lubricating properties of graphite have been known as early as 1906 and the dichalcogenides as early as 1939. [3] Graphite is used extensively in the electrical industry for its good lubrication properties as well as its good electrical conductivity. Graphite is a durable, heavy-duty lubricant that can endure extreme temperature fluctuations ranging from -100 C to 350 C. Graphite has a sheet like structure where the atoms all lie in a plane and are only weakly bonded to the graphite sheets above and below. The C-C bond is strong in 2 dimensions but weak in the third with a hexagonal crystal orientation. Much like a deck of

playing cards, the sheets slide easily. Graphite provides the best wear protection in the presence of moisture.

Dichalcogenides of molybdenum and tungsten

[0008] The dichalcogenides of molybdenum and tungsten meet the successful solid film lubricant criteria very well and have been used extensively and successfully on most space missions (vacuum & temperature extremes) since the late 60's. MoS_2 is a naturally occurring mineral, formed and mined with other ores in various parts of the world. It is highly refined and processed into 0.5-micron average particle size at which time it can be used as a solid lubricant. It possesses the properties of being able to withstand extremely high load capacities up to 600ksi. It is chemically stable, has a very low coefficient of friction, 0.05 to 0.09, in powder form and has thermo-stability from cryogenic temperatures to 350 deg. C. MoS_2 is an ideal solid film lubricant material for extreme environments.

[0009] On an atomic level the dichalcogenide lubricants, have a hexagonal crystal structure with strong cation bonded layers creating a basal plane sandwiched between two weekly bonded anions (Van der Waals forces). The net effect is similar to a deck of cards sliding parallel to the long axis, the sliding axis, producing very low friction between mating surfaces. As a rule of thumb MoS_2 is the preferred lubricant for vacuum/cryogenics and graphite works the best in air, graphite relying on moisture to induce the proper shear.

[00010] The first major milestones in thin solid film lubricant technology are when T. Spalvins in 1967 at NASA Lewis, first reported on the properties of sputter vacuum deposited MoS_2 films and subsequently B.C. Stupp in 1968 started to commercially provide PVD deposited MoS_2 coatings in Dayton, OH. PVD processing resulted in the highest adhesion solid film lubricant coatings.

Soft Metals

[00011] In addition to the dichalcogenide and graphite lamellar type films, soft metals such as Au, Ag, In, Cr, Pb can provide wear protection under extreme conditions and meet the requirements of successful solid film lubrication. Soft metallic lubricants have crystal structures with

multiple slip planes and do not work-harden appreciably during sliding contacts. Dislocations and point defects generated during shear deformation are rapidly nullified by the frictional heat produced during sliding contact. Reported friction coefficients of soft metals range from 0.1 to 0.4, depending on the metal and test conditions. Ion-plated lead films are extensively used in Europe. In solar array drives alone, more than 2 million operational hours in orbit have been accumulated. An important property of the lead film is its high load-carrying ability. Under Hertzian contact, the as-deposited film flows plastically until a thin film (10 Nm thickness or less) remains and then elastically deforms the substrate. In this condition, the film can survive contact loads approaching the static load capacity of a rolling element bearing. Lead coatings have had good success as a solid lubricant in vacuum applications and additionally it is used extensively as a solid film lubricant for the high speed bearing in imaging X-ray tubes under vacuum. Optimum performance of lead and other metals is achieved at approximately 1 um thickness. Silver and indium have been investigated too, but actual usage in space is not reported. Solid lubricant films are used in a variety of mechanisms on various spacecraft and launch vehicles. Deposition of soft metals (Pb, Au, Ag, In) by ion plating provides excellent adhesion. These films have been particularly effective in spacecraft bearings found in solar array drive mechanisms in European satellites, on the Hubble space telescope and the BAXS gear for the International Space Station solar collector gear drive. Gold and silver are used in situations requiring electrical conductivity as well. Sputter-deposited MoS_2 has a lower coefficient of friction than ion-plated Pb 0.01 versus 0.1, which means that MoS_2 components should develop less torque.

[00012] There are other lubricant materials that have been reported, but they only find application in limited conditions. For example, CaF_2, BaF_2 and cesium oxythiomolybdates/tungstates have been used for high temperature lubrication. They become soft and their shear strength decreases as the temperature increases.

[00013] Today there are many industrialized methods of solid film lubricant deposition for extreme environments. The general categories in order of increasing cost, complexity and adhesion are as follows:

- Burnished Powders
- Painting with VOC and Binders
- PVD Vacuum Deposited

[00014] Burnished Powders; Solid film lubricants or other functional materials are mixed and placed on a carrier material such as a cloth, blasting media, inert media or specially designed fixtures. The parts to be coated are then brought in contact with the various media resulting in a film of the solid lubricant on the surface of the part. The lubricant material is marginally adherent to the surface of the part with a mechanical bond at best.

[00015] Painting Methods; Solid film lubricants or other functional materials are mixed with organic solvents as well as binders and parts are coated by paint spray guns, dipping or spin coating. Parts must be grit blasted prior to coating. Blasting results in surface finish degradation as well as fatigue from stress risers. Once the parts have been coated an oven bake out procedure is required to evaporate the solvents as well as cure the binders. These methods require the use of VOC's, and are not environmentally friendly. The bond between the solid film lubricant and the part to be coated is limited by the mechanism of the binder and how well it can glue the solid film lubricant to the surface; this bonding is not very strong and the resultant coating can become thick and affect part tolerances. The binders tend to introduce impurities and increase the coefficient of friction of solid film lubricants versus their pure form.

[00016] Vacuum Methods; Solid film lubricants or other functional materials are Physical Vapor Deposited (PVD) using sputter or ion plating deposition. Parts are placed in a chamber which is evacuated of atmospheric gases by pumps. The functional material cathode is bombarded by ions to dislodge the coating on an atomic scale on to the surface of the parts to be coated. This coating tends to have strong bonding to the part due to the purity of the process but requires expensive

equipment and complex process control. Limitations exist on the size and shape of the parts to be coated based on the chamber size as well as ability to effectively manipulate the part for this line of sight process.

[00017] Solid film lubricants are critical for providing low friction surfaces especially in extreme environments. There exist many patents for applying solid film lubricants in special applications found across the majority of industry. Examples include automotive, internal combustion engines, aerospace, gas turbine engines, molding, glass manufacturing, welding, swaging, bearings, cabling and conveyor systems, cutting and forming tools; and many others. The primary methods of solid film lubricant deposition includes spraying, dipping, rubbing, tumbling or brushing. With these primary deposition methods the solid film lubricant must be added to another medium such as epoxy, resin or wax or grease to achieve some level of adhesion to the part being coated; additionally a post oven bake is required. The addition of such binders results in films which are thick and often brittle. An alternative method is to add solid film lubricants to metallic particles and then to use thermal spray methods to deposit low friction coatings. This method results in only a mechanical bond and often post coating grinding and or polishing is required. Some technologies apply solid film lubricants to the surface of parts by mechanical impingement using sand blasting equipment or tumbling polishing equipment however bonding is very weak and surfaces must be roughened prior to coating to create divots to hold the solid film lubricant. Methods based on PVD do achieve atomistic adhesion and a thin film structure with excellent tribological characteristics however these PVD sputtering process requires expensive vacuum equipment and sophisticated process controls. Solid film lubricants deposited by PVD have the ultimate performance capabilities as well as the smallest market share.

[00018] Thus, there is need and market for a method to durably attach a functional layer to an object having one or more surfaces or to a substrate, that overcomes the above prior art shortcomings.

[00019] There has now been discovered a method for adhering a functional layer to a substrate or 3-D article, by a convenient and low cost method along with a novel product, the laminate so formed.

SUMMARY OF THE INVENTION

[00020] Broadly the present invention provides, a method for durably bonding a layer to a substrate comprising,

a) mounting a bond layer selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide to the substrate and

b) mounting a functional layer onto the bond layer.

[00021] The invention further provides a product with a durably attached functional layer comprising,

a) a substrate,

b) a bond layer selected from the group consisting of a soft oxide, a soft metal, a sulfide, a chalcogenide and a combination of two or more thereof mounted on the substrate and

c) a functional layer mounted on top of the bond layer to provide a durably bonded laminate.

[00022] Definitions:

[00023] By *engineering materials*, as used herein, is meant shaped wood, metal, plastic, elastomer, including rubber, ceramic, coating or composite of one or more thereof.

[00024] By a *soft oxide*, as used herein, is meant a material with a hardness below 6 GPa.

[00025] By *soft metal*, as used herein, is meant one with less than 4 GPa.

[00026] By *functional* layer, as used herein, is meant a material layer that provides new or additional function to a laminate layer or substrate.

[00027] By bonding materials or functional materials, including lubricants, suitable for *burnishing*, as used herein, is meant powder, as described below, that will, at least in part, transfer during contact to the substrate being burnished.

[00028] By *burnishing*, as used herein, is meant to rub a material onto another such as through a ball mill whereby a material rubs another with the agent to be burnished between them - as in a ball colliding with a plate with powder between them; rubbing or polishing (including by hand), or by use of a buffing wheel to burnish an article or surface or by kinetic means in which the particle or powder velocity itself causes the particle to rub against and coat another material or surface.

[00029] By *burnishing means*, as used herein, is meant macro size components used to perform the above burnishing steps, such as metal balls, including ball bearings, marbles or plastic balls, of suitable size for the application, , e.g., having a diameter of 1/32" to 1/2" or more and even irregular sized components, such as walnut shells, that can perform the burnishing steps described above, which can be performed, e.g., in a rotating drum, at a suitable speed or one that vibrates or a combination thereof, as desired.

[00030] By a *powder*, as used herein, is meant a well divided solid having a particle size of 1 nm to 500 μm or more depending on the application. The burnishing agent can be a powder (or compacted powder) that is rubbed onto a surface to coat same, as indicated, e.g., in Figures 1-6, less Figure 2 hereof.

[00031] By a *bond layer*, as used herein, is meant a material that is itself adherent to a substrate and enhances adhesion of subsequent layers such that a functional layer is tenaciously bonded to a substrate through a bond layer.

[00032] Burnishing aside, the functional layer can be deposited on the bond layer (of, e.g., Sb_2O_3) by other methods, such as by magnetron sputtering, thermal spray or other suitable deposition methods, though burnishing is a preferred low cost, convenient method.

[00033] The bond layer can be deposited by methods or combination of methods, such as by PVD or magnetron sputtering or CVD or, thermal spray or other suitable deposition methods

including electro or electroless plating, sol-gel, e-coat powder painting, conventional spray, dip or brush, though burnishing is a preferred low cost, convenient method.

[00034] The functional layer can be deposited on the bonding layer (of, e.g., Sb_2O_3) by other methods or combination of methods, such as by PVD or magnetron sputtering or CVD, thermal spray or other suitable deposition methods including electro or electro-less plating, sol-gel, e-coat powder painting conventional spray, dip or brush, though, again, burnishing is a preferred low-cost, convenient method.

BRIEF DESCRIPTION OF THE DRAWINGS

[00035] The invention will become more apparent from the following detailed specification and drawings in which;

[00036] Figure 1 is an elevation schematic view showing a method step embodying the present invention;

[00037] Figure 2 is a fragmentary elevation schematic view showing an alternate method step embodying the present invention,

[00038] Figure 3 is an elevation schematic view of a first step embodying the inventive method,

[00039] Figure 4 is an elevation schematic view of a second step embodying the inventive method,

[00040] Figure 5 is a fragmentary perspective schematic view of a first step of another embodiment of the inventive method and

[00041] Figure 6 is a fragmentary perspective schematic view of a second step of another embodiment of the inventive method.

DESCRIPTION OF PREFERRED EMBODIMENTS

[00042] Referring now in detail to the drawings, examples of applying a bond coat to the surface of a substrate are shown in Figures 1 & 2. That is, on a substrate 10, a precursor bondable powder 12 is applied to the surface 14 of the substrate 10, as shown in the Figure 1. Such layer 12 is in the form of Sb_2O_3 powder which, after application to the surface 14, is burnished thereon by burnishing tool 16 to form bond coat 18, as shown in Figure 1.

[00043] Alternatively, within the scope of the present invention, such bond coat can be applied to a substrate by a non-burnishing method, such as sputtering, as shown in Figure 2. That is, an electrode 20 of Sb_2O_3, is spaced from a substrate 22 in an atmosphere of Argon, the ions 24 of which are attracted to the Sb_2O_3 electrode, which frees Sb_2O_3 ions, which are attracted to the surface 26 of substrate 22, causing Sb_2O_3 to coat said surface 26 with a bond coat 28, as shown in Figure 2 hereof.

[00044] In a further embodiment of the method of the invention, substrate 30 has on its surface 32, a bond coat 34 of Sb_2O_3, per Figure 3, formed by either of the methods described above with respect to Figures 1 & 2.

[00045] Then, as shown in Figure 4, a functional layer, such as a solid layer of lubricant 36, is deposited on the bond coat 34, which holds the lubricant layer 36 in a strong durable bond, a bond, which would not be durable without the bond coat 34 provided by the method of the present invention, which also provides the novel products of the present invention, i.e., the durably bonded laminate 35 of Figure 3 and the durably bonded laminate 37, per Figure 4 hereof.

[00046] Also, per the invention, 3-D articles can be coated in a production system by machinery, such as shown in Figures 5 and 6. That is, ball mill 40, having rotatable drum 42, receives Sb_2O_3 bonding material 44, milling beads 45 and gears 46, the objects to be coated per Figure 5 hereof.

[00047] The drum 40 is rotated, as shown in Figure 5, which causes the bonding material 44 to contact the gears 46 and the beads 45 to come into repetitive contact with bonding material and

gears so as to coat, burnish and build up a coating of Sb_2O_3 on the gears 46 in a manner similar to the bond coat 34, shown on substrate 35 in Figure 3.

[00048] Thereafter, the now bond-coated gears 48 are transferred to the second coating stage, ball mill 50, having rotatable drum 52. Here, the coated gears 48 are placed in the drum 52 along with functional material, such as lubricant 54 and beads 56. The drum 50 is rotated, as indicated in Figure 6, and, in the manner described above re drum 40, the lubricant material 54 is coated and burnished upon the coated gears 48, to build up the lubricant as a second coating thereon, in a manner similar to the buildup of functional layer 36 on substrate 37, per Figure 4 hereof.

[00049] Thus, numerous 3-D objects or articles can be coated with the above layers or coatings by ball mills, a vibratory or other machine, in a mass production system per the invention.

[00050] Thus, the invention provides a substrate with a bond coat thereon, as an intermediate layer (as a first laminate), which layer can receive and hold fast, an added layer mounted on such bond coat (as a second laminate). The added layer can be a functional layer, such as a solid lubricant layer or other functional layer as described herein.

[00051] The inventive method can be a non-vacuum, ambient temperature, deposition process that does not involve binders, adhesives, curing or baking. However, applying the soft bond coat material (e.g., Sb_2O_3) by any method (including vacuum methods) provides benefit. A significant advantage of the bond coat is that it allows the lubricant to be deposited by burnishing and still provide low friction and long life wear protection. The chemical/physical bonding insures that the coating does not chip, crack or peel. Industrial friction and wear testing of this molecular bonding of solid film lubricants has demonstrated the superlative nature of this process.

[00052] The thickness of the bond layer herein or the functional layer herein is related to the particle size employed in the respective layers. Thus, the particle size influences the layer thickness and so the range of each can be from 1 nm to 500 μm, depending upon the application of the functional coating. That is, the bond coating and the functional coating can be smaller or less thick

where the functional coating is a lubricant and of greater thickness where the functional coating is a catalyst. Within the above range, a preferred range of the respective layers, as noted above, is .5 to 3.0 μm thick, which includes about 1 μm, which will not affect part tolerances.

[00053] The basic process is as follows:

1. Surface of the substrate is properly cleaned of surface contaminants
2. The clean surface can be further activated as appropriate, acid for metals and ceramics and plasma treatment for composites and plastics
3. A thin layer of a soft oxide material such as Sb_2O_3 is burnished on to the surface such that a uniform film is produced.
4. This can be done by many methods:
    a. Rubbing with soft clothes
    b. Vibratory tumbler with media such as ceramic, wood, corn, plastic, steel, and the like
    c. Brushing including sonic brushes
    d. Dipping
    e. Spin coating
    f. Spraying using conventional paint methods or electrostatic methods
    g. Warm Spraying or thermal spraying
    h. Plasma PVD or CVD
    i. Sol-Gel
    j. Blast impingement
    k. Buffing wheels
    l. Any loose, non-adherent material is cleaned off

[00054] The solid film lubricant is then deposited on top of the soft oxide bond layer film.

[00055] The solid film lubricant can be MoS_2, WS_2 (the dichalcogenides in general), ZnO (and oxides in general) boron nitride, CaF_2, graphite and mixtures of these solid lubricants as well as performance enhancing additives, PTFE or any other friction reducing material

[00056] The solid film lubricant can be deposited by a similar method as the bond treatment

[00057] This can be done by many methods, for example:

a. Rubbing with soft clothes

b. Vibratory tumbler with media such as ceramic, wood, corn, plastic, steel, and the like

c. Brushing including sonic brushes

d. Dipping

e. Spin coating

f. Spraying using conventional paint methods or electrostatic methods

g. Warm Spraying or thermal spraying

h. Plasma PVD or CVD

i. Sol-Gel

j. Blast impingement

k. Buffing wheels

l. Any loose, non-adherent material is cleaned off.

[00058] Thus, a significant advance in the performance of solid film lubricants has been made by the discovery of coating deposition processes for selected materials that results in higher adhesion and higher performance (lower friction and reduced wear) than PVD deposited coatings. PVD is generally considered the gold standard. It is this advancement that is the subject of this invention: a novel surface treatment method by which functional coatings such as adaptive and conventional solid film lubricants can be bonded to engineered materials with superior adhesion.

[00059] The method of the invention thus creates a bond coat for applying solid film lubricants or other functional coatings to the surface of engineered materials. The process is useful

with selected materials that create good lubricant bonding and allows the lubricant to spread and be trapped in reservoirs and otherwise act synergistically with the bond coat to lower friction and wear. For example, antimony trioxide (material part of the process-material pairing) can be burnished (process) onto an engineering component. MoS_2/graphite/Sb_2O_3 (lubricant) mixtures, for example, can then be burnished on top (of the inventive bond layer herein, including Sb_2O_3), forming an adherent, long life, low friction surface. Without the surface treatment (i.e., without the bond layer of the invention), the system fails quickly. Using the same lubricant and applying by PVD, the lifetime improves, but considerable cost and loss of flexibility is incurred. Deposition of the soft bond layer material can be accomplished by a variety of methods, both chemical and physical in nature. The material can be deposited by rubbing a rotating part or rotating applicator, by brushes, wheels or polishing tables. A vibratory tumbler or rocking shaker can be used as well as spraying, thermal spraying or dipping techniques. Burnishing Sb_2O_3 on to a surface is one embodiment that is convenient, low cost and provides durable benefit.

[00060] As previously noted, solid film lubricants have shown great success in providing lubrication and wear protection in a broad range of industries as well as applications; specifically in harsh environments where conventional liquid or grease based lubricants cannot be used. The limiting factor of solid film lubricants has often been poor adhesion. Historically to achieve adhesion parts had to be roughened by blasting or binders and solvents had to be used with oven bake procedures, all resulting in marginal adhesion of the solid film lubricant to the substrate. An alternate method has been to use vacuum plasma based technologies with high expense, process complexity and limitation on the size of parts. The subject of this invention provides durable adhesion of solid film lubricants and a synergistic effect is achieved, creating a low friction, low wear and a long lived lube surface. A significant advantage of the burnished Sb_2O_3 embodiment is that it is convenient, an environmentally friendly process, scalable and permits the lubricant to be burnished (inexpensive, environmentally friendly and scalable) onto the surface. A burnished

lubricant that is as effective or more so, than PVD or CVD lubricant coatings at a significant cost savings.

[00061] As indicated, a novel surface deposition method for selected materials is provided, which enables lubricants and other functional materials to be applied to engineered surfaces with surpassing adhesion and enhanced lubricant properties. A focus of this invention has been on solving tribological problems by the use of solid film lubricants. Another industry that can benefit from this bonding process of materials in powder form is electroluminescent materials for sensors, detectors, scintillators and displays.

[00062] Thus a low cost method is provided that, in one embodiment, prepares a surface to tightly bond a coating, such as a lubricant layer, that lowers friction and protects such surface from wear. In addition, the bond coat process and materials act synergistically with the lubricant to provide markedly improved properties. Essentially, a bond layer is created that chemically and physically bonds lubricants to a substrate (e.g., MoS_2, WS_2 (the dichalcogenides in general), ZnO (and oxides in general), boron nitride, cesium oxythiomolybdate, CaF_2, graphite and mixtures of these solid lubricants), that results in improved adhesion, lubricant availability, lower friction and extended lifetime thereof. Materials adhere better and the lubrication mechanism is enhanced as the lubricant spreads and remains on the coated surfaces. The process and bond coat work on various substrates, including, metals, ceramics, plastics, composites and engineered materials in general.

[00063] Lubricants that adhered poorly to these substrates before application of the inventive process/coating, adhere tenaciously afterwards. The process extends the life of coatings and lowers friction by several orders of magnitude compared to depositing coatings without the bond layer. One embodiment of the invention permits bonding by a method of burnishing a special oxide such as antimony trioxide. The bonding has superior characteristics to even plasma vacuum technologies, which is a complex and expensive process. The invention permits the lubricant coat to be applied by burnishing and yet provide the superior performance of PVD coatings. The burnishing process is significantly less expensive than vacuum based processes. The process in this invention can be

described as a non-vacuum, ambient temperature, deposition process that does not involve binders, adhesives, curing or baking - no hazardous solvents or hazardous air pollutants. However, temperatures above and below the ambient can be employed in the coating steps herein, as desired, within the scope of the invention.

[00064] As previously noted, the invention provides a coating that does not chip, crack or peel. The final functional coating is preferably about 1 µm thick (with a range of .5-3.0 µm), which will not affect part tolerances. Industrial grade friction and wear testing of solid film lubricants has demonstrated the superlative nature of this process. Solid film lubricants have shown great success in providing lubrication and wear protection in a broad range of applications and would benefit many industries. Benefits are specifically notable in harsh environments where conventional liquid or grease based lubricants can not be used. It is also noted that the process is inexpensive, environmentally friendly and uncomplex compared to other methods used to achieve improvements in solid lubricant performance. A limiting factor of solid film lubricants has been poor adhesion and limited lifetime. Historically, to achieve adhesion, parts had to be roughened by blasting or binders and solvents had to be used with oven-bake procedures, all resulting in marginal adhesion of the solid film lubricant to the substrate. An alternate method has been to use vacuum plasma based technologies with high expense, process complexity and limitation on the size of parts. The subject of this invention provides strong adhesion of solid film lubricants in a synergistic manner creating a low friction, low wear, and long life surface. The process is completely scalable to large and complex parts.

[00065] An entire industry exists for solid film lubricants. They are deposited by conventional "paint" methods (i.e., in a binder), or by complex vacuum methods. Nothing in the current art or science has the adhesion, cohesion and performance characteristics as does the subject of this invention. A number of bond coats are used, but none are burnished, which is key, none are soft oxides or other burnishable soft compounds - in particular none are antimony trioxide. Bond coats

described outside this invention include metals and phosphate treatments, but again, not burnished oxides and soft materials.

[00066] The method of the present invention applies to enhancing moving mechanical components in standard or harsh environments such as gas turbine engines, rocket engines, space-based mechanisms, munitions; anywhere a low friction and low wear surface is required. Gears, splines, bearings, deployable structures (particularly in space), bushings, guides, slides, shafts, rings, pins, pistons, camshafts, hinges, seals are all components where this invention can find use.

[00067] In sum, reducing friction and wear has a tremendous payoff, for any application involving moving mechanical components needs lubrication. Extending the realm of solid film lubricant applications by providing a process that joins solid lubricants to functional surfaces has windfall effects through out all of industry. One-third of all usable, device-produced energy is lost to friction and wear and reactive maintenance costs three times that of planned maintenance, costing industry and consumers billions each year.

[00068] Finally, while durably mounted lubricant layers are an important embodiment of the present invention, other functional layers are provided, per the invention, such as hard particle durable material, anti-corrosion compound, catalyst, photosensitive material, adsorbent, photovoltaic material, and sensor compounds.

WHAT IS CLAIMED IS:

1. A method for durably bonding a layer to a substrate comprising,

a) mounting a bond layer selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide to said substrate and

b) mounting a functional layer onto said bond layer.

2. The method of claim 1 wherein said substrate is selected from the group consisting of metals, ceramics, plastics, coatings, cellulose, composites and combinations thereof.

3. The method of claim 1 wherein said soft oxide is selected from the group consisting of Sb_2O_3, ZnO, CdO, and PbO.

4. The method of claim 1 wherein said functional layer is selected from the group consisting of a lubricant, hard-particle coating, anti-corrosive layer, catalyst, photosensitive material, adsorbent material, photovoltaic material and a sensor-containing layer.

5. The method of claim 4 wherein said lubricant is selected from the group consisting of ZnO, the dichalcogenides, boric acid, boron oxide, polytetrafluoroethlene (Teflon ™), PbO, fullerene, carbon nanostructures, carbon fluoride, boron nitride, cesium oxythiomolybdate, CaF_2, graphite and mixtures thereof, as well as films of soft metals; Au, Ag, In, Cr & Pb and oxides thereof, which can provide successful solid film lubrication and wear protection.

6. The method of claim 5 wherein said dichalcogenides are MoS_2 or WS_2.

7. The method of claim 1 wherein said lubricant layer has nanoparticles therein.

8. A method for durably bonding a functional layer to a surface comprising,

a) adhering a bond layer selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide, to said surface and

b) depositing a functional layer onto said bond layer.

9. The method of claim 8 wherein said bond layer is Sb_2O_3.

10. The method of claim 8 comprising, depositing said functional layer as a lubricant powder onto said bond layer and burnishing same thereon, to obtain a lubricant layer well adhered to said surface by said bond layer.

11. The method of claim 10 wherein a bond layer, topped by a lubricant layer, are installed on two sides of an object, each of which lubricant layers are so burnished by hand or machine.

12. The method of claim 10 wherein said surface is of metal and said bond layer is Sb_2O_3 and said lubricant is graphite powder, a mixture of graphite/Sb_2O_3 and MoS_2 or of graphite and MoS_2 .

13. A product with a durably attached functional layer comprising,

a) a substrate,

b) a bond layer selected from the group consisting of a soft oxide, a soft metal, a sulfide a chalcogenide and a combination of two or more thereof mounted on said substrate and

c) a functional layer mounted on top of said bond layer to provide a durably bonded laminate.

14. The product of claim 13 wherein said substrate is selected from the group consisting of metals, ceramics, plastics, coatings, cellulose, composites and combinations thereof.

15. The product of claim 13 wherein said surface is of metal and said bond layer is antimony oxide and said lubricant is graphite powder, a mixture of graphite/Sb_2O_3 and MoS_2 or of graphite and MoS_2.

16. The product of claim 13 wherein said soft oxide is Sb_2O_3, ZnO, CdO or PbO,

17. The product of claim 13 wherein said functional layer is selected from the group consisting of a lubricant, hard particle coating, anti-corrosive layer, catalyst, photosensitive material, adsorbent, photovoltaic material and a sensor-containing layer.

18. A method for durably coating one or more objects on two or more sides comprising,

a) adding a bonding material into a mixing vessel,

b) adding said one or more objects into said vessel,

c) adding burnishing means into said vessel,

d) rotating said vessel to burnish and coat said one or more objects with said bonding material on a plurality of sides and

e) repeating the above method so as to add a functional layer on said bond coating on said one or more objects in the same or in a different vessel to arrive at one or more objects which have coatings on at least two sides thereof in the form of two stacked layers, durably bonded to said one or more objects.

19. The method of claim 18 wherein said one or more objects are each coated with a bond layer in a first vessel and said functional layer is added on top of said bond layer in a second vessel.

20. The method of claim 18 wherein said objects are components of machines, vehicles or structures, which act as substrates that can be of metals, ceramics, plastics, coatings, cellulose, composites and combinations thereof.

21. The method of claim 18 wherein said bonding material is selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide.

22. The method of claim 18 wherein said functional layer is selected from the group consisting of a lubricant, hard-particle coating, anti-corrosive layer, catalyst, photosensitive material, adsorbent, photovoltaic material, and a sensor-containing layer.

23. The method of claim 18 wherein said lubricant is selected from the group consisting of zinc oxide, the dichalcogenides, boric acid, boron aside a, polytetrafluoroethlene (Teflon ™), PbO, fullerene, carbon nanostructures, carbon fluoride, boron nitride, cesium oxythiomolybdate, CaF_2, graphite and mixtures thereof, as well as films of soft metals; Au, Ag, In, Cr & Pb and oxides thereof, which can provide successful solid film lubrication and wear protection.

24. The method of claim 18 wherein said burnishing means are beads.

25. The method of claim 4 wherein said hard-particle coating contains boron nitride.

AMENDED CLAIMS
received by the International Bureau on 13 August 2009 (13.08.09)

1. A method for durably bonding a layer to a substrate comprising, mounting a bond layer of material selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide onto said substrate, said bond layer being substantially binder-free to permit direct contact of said material with said substrate for enhanced bonding thereof.

2. The method of claim 1 wherein a functional layer is mounted onto said bond layer for bonding to said substrate.

3. The method of claim 1 wherein said substrate is selected from the group consisting of metals, ceramics, plastics, coatings, cellulose, composites and combinations thereof.

4. The method of claim 1 wherein said soft oxide is selected from the group consisting of Sb_2O_3, ZnO, CdO, and PbO.

5. The method of claim 2 wherein said functional layer is selected from the group consisting of a lubricant, hard-particle coating, anti-corrosive layer, catalyst, photosensitive material, adsorbent material, photovoltaic material and a sensor-containing layer.

6. The method of claim 5 wherein said lubricant is selected from the group consisting of ZnO, the dichalcogenides, boric acid, boron oxide, polytetrafluoroethlene (Teflon ™), PbO, fullerene, carbon nanostructures, carbon fluoride, boron nitride, cesium oxythiomolybdate, CaF_2, graphite and mixtures thereof, as well as films of soft metals; Au, Ag, In, Cr & Pb and oxides thereof, which can provide successful solid film lubrication and wear protection.

7. The method of claim 6 wherein said dichalcogenides are MoS_2 or WS_2,

8. A method for binding a functional layer to a surface comprising, mounting a bond layer of material selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide to said surface and mounting a functional layer to said bond layer, said bond layer being substantially binder-free to permit direct contact of said material with said surface and with said functional layer for enhanced bonding to both.

9. A method for durably bonding a functional layer to a surface comprising,

a) adhering a bond layer of material selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide, to said surface, said bond layer being substantially binder-free to permit direct contact of said material with said surface for enhanced bonding thereof and

b) depositing a functional layer onto said bond layer.

10. The method of claim 9 wherein said bond layer is Sb_2O_3.

11. The method of claim 9 comprising, depositing said functional layer as a lubricant powder onto said bond layer and burnishing same thereon, to obtain a lubricant layer well adhered to said surface by said bond layer.

12. The method of claim 11 wherein a bond layer, topped by a lubricant layer, are installed on at least two sides of an object, each of which lubricant layers are so burnished by hand or machine.

13. The method of claim 11 wherein said surface is of metal and said bond layer is Sb_2O_3 and said lubricant is graphite powder, a mixture of graphite/Sb_2O_3 and MoS_2 or of graphite and MoS_2 .

14. A durably attached product comprising,

a) a substrate and

b) a bond layer of material selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide mounted on said substrate, said bond layer being substantially binder-free to permit direct contact of said material with said substrate for enhanced bonding thereof.

15. The product of claim 14 having a functional layer mounted on top of said bond layer to provide a durably bonded laminate with said substrate.

16. The product of claim 14 wherein said substrate is selected from the group consisting of metals, ceramics, plastics, coatings, cellulose, composites and combinations thereof.

17. The product of claim 15 wherein said surface is of metal and said bond layer is antimony oxide and said functional layer is a lubricant of graphite powder, a mixture of graphite/Sb_2O_3 and MoS_2 or of graphite and MoS_2

18. The product of claim 14 wherein said soft oxide is Sb_2O_3, ZnO, CdO or PbO.

19. The product of claim 15 wherein said functional layer is selected from the group consisting of a lubricant, hard particle coating, anti-corrosive layer, catalyst, photosensitive material, adsorbent, photovoltaic material and a sensor-containing layer.

20. A method for durably coating one or more objects on two or more sides comprising,

a) adding a bonding material into a mixing vessel, said bonding material being substantially binder-free to permit direct contact of said material with said one or more objects for enhanced bonding thereto,

b) adding said one or more objects into said vessel,

c) adding burnishing means into said vessel and

d) rotating said vessel to burnish and coat said one or more objects with said bonding material on a plurality of sides.

21. The method of claim 20 comprising, adding a functional layer on said bond coating on said one or more objects in the same or in a different vessel, to arrive at one or more objects which have coatings on at least two sides thereof in the form of stacked layers, durably bonded to said one or more objects.

22. The method of claim 21 wherein said one or more objects are each coated with a bond layer in a first vessel and said functional layer is added on top of said bond layer in a second vessel.

23. The method of claim 21 wherein said objects are components of machines, vehicles or structures, which act as substrates that can be of metals, ceramics, plastics, coatings, cellulose, composites or combinations thereof.

24. The method of claim 20 wherein said bonding material is selected from the group consisting of a soft oxide, a soft metal, a sulfide and a chalcogenide.

25. The method of claim 21 wherein said functional layer is selected from the group consisting of a lubricant, hard-particle coating, anti-corrosive layer, catalyst, photosensitive material, adsorbent, photovoltaic material and a sensor-containing layer.

26. The method of claim 25 wherein said lubricant is selected from the group consisting of zinc oxide, the dichalcogenides, boric acid, boron aside, polytetrafluoroethlene (Teflon ™), PbO, fullerene, carbon nanostructures, carbon fluoride, boron nitride, cesium oxythiomolybdate, CaF_2, graphite and mixtures thereof, as well as films of soft metals; Au, Ag, In, Cr & Pb and oxides thereof, which can provide solid film lubrication and wear protection.

27. The method of claim 20 wherein said burnishing means are beads.

28. The method of claim 5 wherein said hard-particle coating contains boron nitride.

29. The method of claim 5 wherein said lubricant has nanoparticles therein.

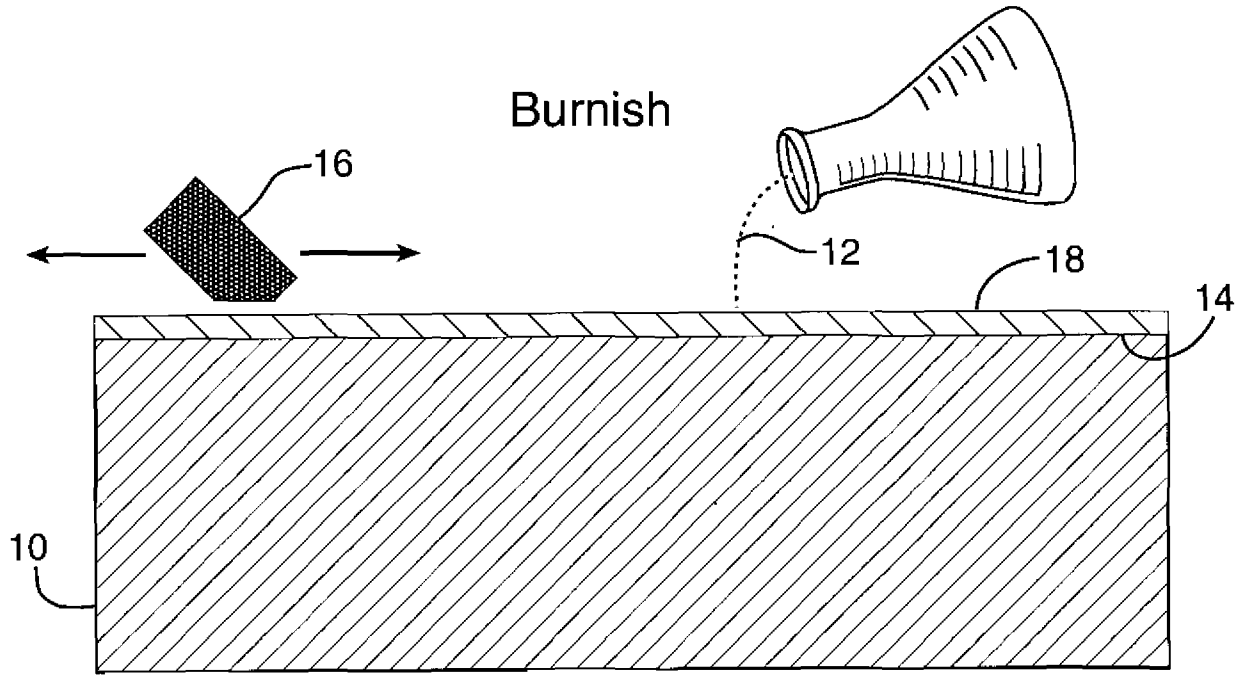

Burnish
16
12
18
14
10

Fig. 1

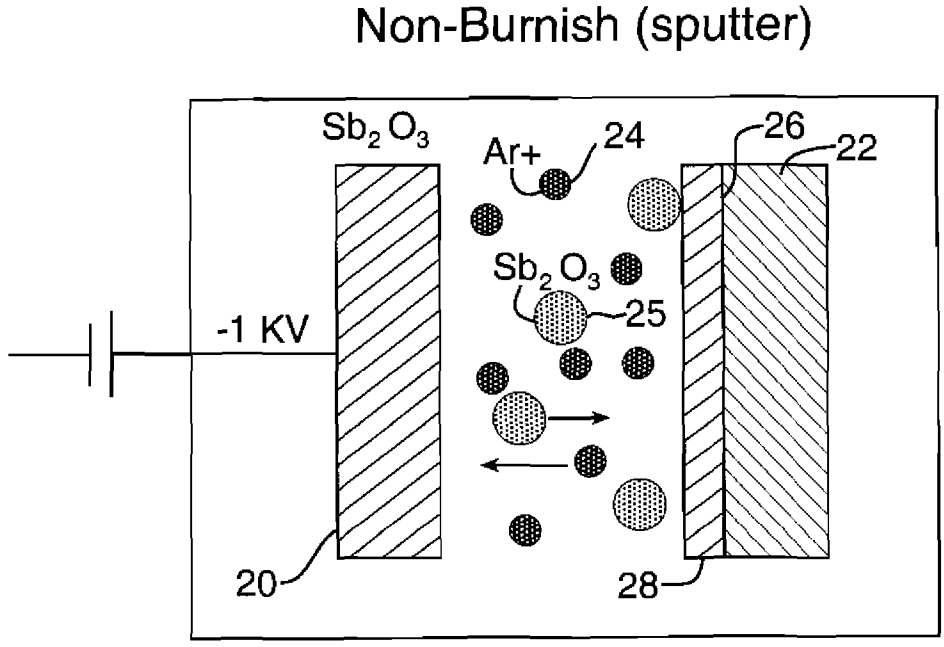

Non-Burnish (sputter)
Sb_2O_3
Ar+
24
26
22
Sb_2O_3
25
-1 KV
20
28

Fig. 2

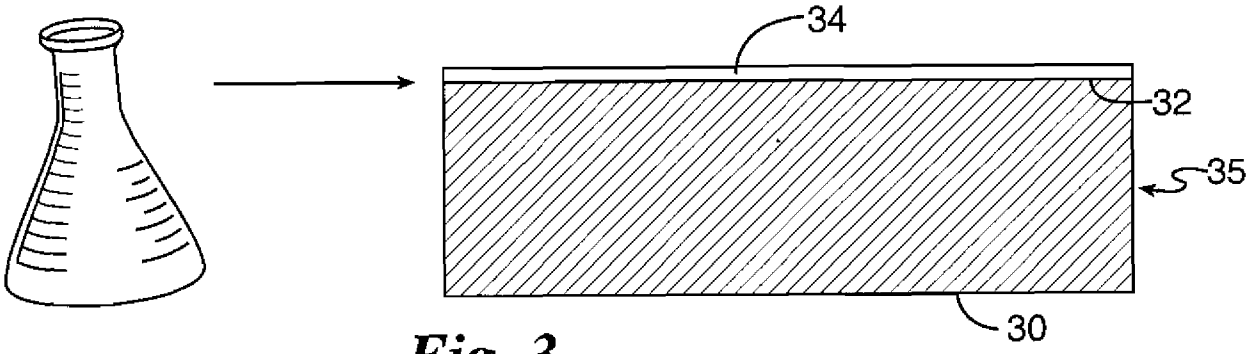


Fig. 3

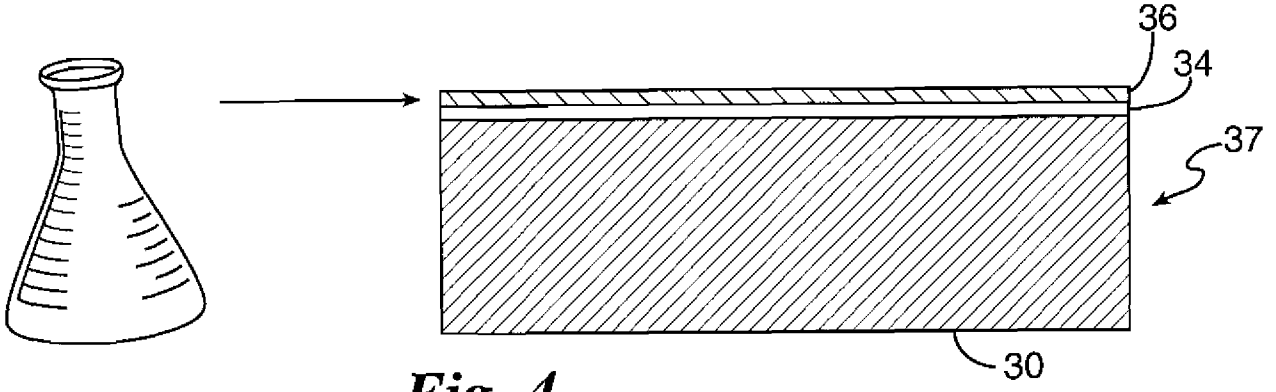


Fig. 4

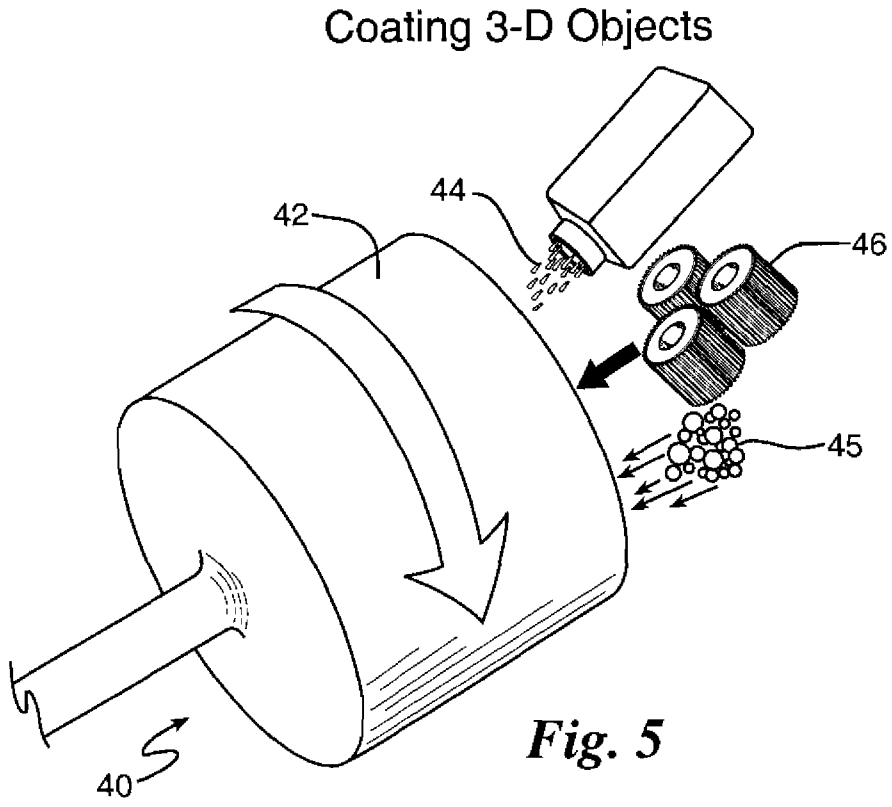


Fig. 5

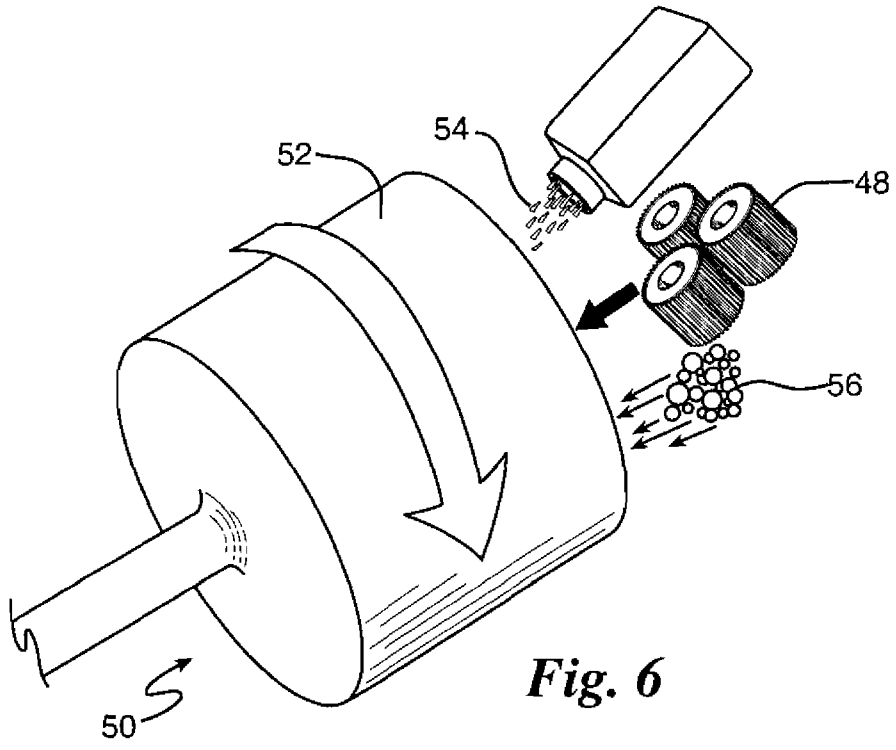


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/38931

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B42C 11/00 (2009.01)
USPC - 412/4; 281/21.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (8) - B42C 11/00 (2009.01)
USPC - 412/4; 281/21.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PUBWEST (PGPB,USPT,USOC,EPAB,JPAB) Terms - layers metal bond coat solid lubricant mill peen cold burnish oxide CdO PbO ZnO Sb2O3 chalcogenide
Google - MoS2 bonded layer burnish; soft metal bonding layer mill; metal bonding layers CdO; chalcogenide bond layers

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2,990,294 A (LONG) 27 June 1961 (27.07.1961), col 2, ln 27-35; col 4, ln 14-24; col 6, ln 42 -49; col 7, ln 10-20; col 8, ln 37-40;	1-6, 8-9, 13-14, 16-17 --- 7, 10-12, 15, 18-25
Y	US 5,407,590 A (SALVIA) 18 April 1995 (18.04.1995), col 1, ln 50-53; col 2, ln 18-23; col 2, ln 62-65; col 3, ln 4-9; col 3, ln 40-54	7, 10-11, 18-25
Y	EP 1 304 493 A1 (KAWAGOE, ET AL) 23 April 2003 (23.04.2003), para [0011]	12, 15

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 May 2009 (27.05.2009)	16 JUN 2009

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774