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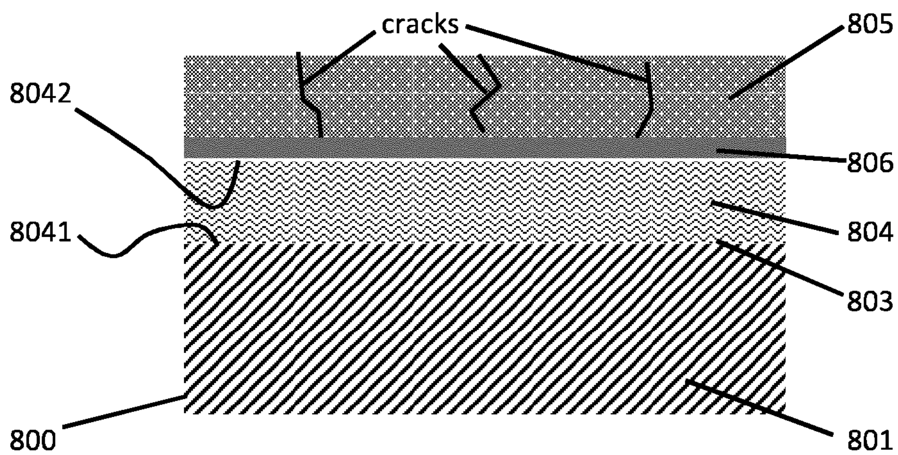
# (54) CORROSION AND FATIGUE RESISTANT COATING FOR A NON-LINE-OF-SIGHT (NLOS) PROCESS

(57) A non-line-of-sight (NLOS) coating process is provided for a substrate having first and second transverse surfaces where the second surface lacks a LOS for depositional processing. The NLOS coating process includes electroplating or electroless plating a crack-resistant interlayer coating to at least the second surface and applying a wear-resistant coating to the crack-resistant interlayer coating by electrolytic or electroless plating.

FIG. 10

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## Description

BACKGROUND

**[0001]** The following description relates to corrosion and fatigue resistant coatings and, more particularly, to corrosion and fatigue resistant coatings for a non-line-of-sight (NLOS) process.

**[0002]** Hard coatings are often used to impart wear resistance to a substrate in a variety of applications. These include, for example, automotive cylinders, hydraulic actuators, aircraft landing gear and precision valves. The coatings provide a level of protection from the operating environment which would otherwise lead to abrasive, adhesive or erosive wear. The coatings may be used with a variety of substrate materials such as stainless steels, carbon steels, titanium alloys, nickel based superalloys, aluminum alloys or magnesium alloys.

**[0003]** In cases where abrasive wear is a major concern, the coatings serve to defeat damage that would be caused by entrained particulate matter. The coatings do this by, among other things, providing resistance to penetration cutting damage when particles are captured between contacting surfaces. In erosive wear cases, the coatings resist penetration and damage to the substrate and, in some cases, can fracture the impinging particulate. In adhesive wear cases, the coatings can serve to lower the coefficient of friction of a counterface, for instance, in a metal-to-metal contact situation where material couples would otherwise be metallurgically compatible and have a propensity to adhere to one another under contact stress.

BRIEF DESCRIPTION

**[0004]** According to one aspect of the disclosure, a non-line-of-sight (NLOS) coating process is provided (e.g. a process for producing a coated article as herein described) for a substrate having first and second transverse surfaces where the second surface lacks a LOS for depositional processing. The NLOS coating process includes electroplating or electroless plating a crack-resistant interlayer coating to at least the second surface and applying a wear-resistant coating to the crack-resistant interlayer coating by electrolytic or electroless plating.

**[0005]** In accordance with additional or alternative embodiments, the substrate defines a bore-hole and the second surface is an interior facing surface of the bore-hole.

**[0006]** In accordance with additional or alternative embodiments, the substrate includes at least one or more of stainless steels, carbon steels, titanium alloys, nickel based superalloys, aluminum alloys and magnesium alloys and the crack-resistant interlayer coating has a low elastic modulus and/or a high fracture toughness as compared to the substrate.

**[0007]** In accordance with additional or alternative embodiments, the crack-resistant interlayer coating is porous.

**[0008]** In accordance with additional or alternative embodiments, the crack-resistant interlayer coating includes at least one of zinc (Zn), tin (Sn), tin-zinc (Sn-Zn), silver (Ag), indium (In), bismuth (Bi), gold (Au), lead (Pb), cadmium (Cd) and aluminum (Al).

**[0009]** In accordance with additional or alternative embodiments, the electrolytic or electroless plating includes nickel plating.

**[0010]** In accordance with additional or alternative embodiments, the wear-resistant coating includes at least one of chromium (Cr), cobalt phosphorus (Co-P), nickel tungsten (Ni-W), nickel (Ni), cobalt (Co), nickel cobalt (Ni-Co), nickel boron (Ni-B) and nickel phosphorus (Ni-P).

**[0011]** In accordance with additional or alternative embodiments, the wear-resistant coating further includes boron nitride (BN) or cubic BN, diamonds, chromium carbide ($Cr_3C_2$) and silicon carbide (SiC).

**[0012]** In accordance with additional or alternative embodiments, the NLOS coating process further includes at least one of interposing a corrosion-resistant coating between the substrate and the crack-resistant interlayer coating and interposing the corrosion-resistant coating between the crack-resistant interlayer coating and the wear-resistant coating.

**[0013]** In accordance with additional or alternative embodiments, where the corrosion-resistant coating is interposed between the substrate and the crack-resistant interlayer coating, the corrosion resistant coating comprises at least one of zinc (Zn), tin (Sn) and tin-zinc (Zn-Sn), and, where the corrosion-resistant coating is interposed between the crack-resistant interlayer coating and the wear-resistant coating, the corrosion-resistant coating comprises at least one of nickel phosphorous (Ni-P), nickel (Ni), Zn, Sn, Sn-Zn and zinc nickel (Zn-Ni).

**[0014]** According to another aspect of the disclosure, a non-line-of-sight (NLOS) coating process (e.g. a process for producing a coated article as herein described) is provided. The NLOS coating process includes providing a substrate (e.g. a substrate as herein defined) having first and second transverse surfaces, the second surface lacking a LOS for depositional processing, electroplating or electroless plating a crack-resistant interlayer coating having first and second opposite interfaces proximate to at least the second surface such that the first interface faces the second surface, applying a wear-resistant coating to the second interface of the crack-resistant interlayer coating by electrolytic or electroless plating and at least one of interposing a corrosion-resistant coating between the second surface and the first interface of the crack-resistant interlayer coating and interposing the corrosion-resistant coating between the crack-resistant interlayer coating and the wear-resistant coating.

**[0015]** According to another aspect of the disclosure, a coated article is provided, e.g. an article coated according to the process described herein. The coated article includes a substrate (e.g. a substrate as herein defined) having first and second transverse surfaces, the second surface lacking a LOS for depositional processing, a crack-resistant interlayer coating which is electroplated or electroless plated to at least the second surface and a wear-resistant coating which is electrolytically or electrolessly plated to the crack-resistant interlayer coating.

**[0016]** In accordance with additional or alternative embodiments, the substrate defines a bore-hole and the second surface is an interior facing surface of the bore-hole.

**[0017]** In accordance with additional or alternative embodiments, the substrate includes at least one or more of stainless steels, carbon steels, titanium alloys, nickel based superalloys, aluminum alloys and magnesium alloys and the crack-resistant interlayer coating has a low elastic modulus and/or a high fracture toughness as compared to the substrate.

**[0018]** In accordance with additional or alternative embodiments, the crack-resistant interlayer coating is porous.

**[0019]** In accordance with additional or alternative embodiments, the crack-resistant interlayer coating includes at least one of zinc (Zn), tin (Sn), tin-zinc (Sn-Zn), silver (Ag), indium (In), bismuth (Bi), gold (Au), lead (Pb), cadmium (Cd) and aluminum (Al).

**[0020]** In accordance with additional or alternative embodiments, the wear-resistant coating includes at least one of chromium (Cr), cobalt phosphorus (Co-P), nickel tungsten (Ni-W), nickel (Ni), cobalt (Co), nickel cobalt (Ni-Co), nickel boron (Ni-B) and nickel phosphorus (Ni-P).

**[0021]** In accordance with additional or alternative embodiments, the wear-resistant coating further includes boron nitride (BN) or cubic BN, diamonds, chromium carbide ($Cr_3C_2$) and silicon carbide (SiC).

**[0022]** In accordance with additional or alternative embodiments, the coated article further includes at least one of interposing a corrosion-resistant coating between the substrate and the crack-resistant interlayer coating and interposing the corrosion-resistant coating between the crack-resistant interlayer coating and the wear-resistant coating.

**[0023]** In accordance with additional or alternative embodiments, where the corrosion-resistant coating is interposed between the substrate and the crack-resistant interlayer coating, the corrosion resistant coating comprises at least one of zinc (Zn), tin (Sn) and tin-zinc (Zn-Sn), and, where the corrosion-resistant coating is interposed between the crack-resistant interlayer coating and the wear-resistant coating, the corrosion-resistant coating comprises at least one of nickel phosphorous (Ni-P), nickel (Ni), Zn, Sn, Sn-Zn and zinc nickel (Zn-Ni).

**[0024]** These and other advantages and features will become more apparent from the following description taken in conjunction with the drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0025]** The subject matter, which is regarded as the disclosure, is particularly pointed out and distinctly claimed in the claims at the conclusion of the specification. The foregoing and other features, and advantages of the disclosure are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a side view of a line-of-sight (LOS) depositional process;

FIG. 2 is a side view of a non-line-of-sight (NLOS) case in which the depositional process of FIG. 1 is at least somewhat inappropriate;

FIG. 3 is a side view of a NLOS case in which a substrate includes first and second transverse surfaces in accordance with embodiments;

FIG. 4 is a side view of a crack-resistant interlayer coating that is applied to at least the second surface of FIG. 3 in accordance with embodiments;

FIG. 5 is a side view of a wear-resistant coating that is applied to the crack-resistant coating of FIG. 4 in accordance with embodiments;

FIG. 6 is an enlarged view of the encircled portion of the wear-resistant coating of FIG. 5;

FIG. 7 is a side view of a corrosion-resistant coating interposed between a substrate and a crack-resistant coating in accordance with embodiments;

FIG. 8 is an enlarged side view of a coated article in accordance with embodiments;

FIG. 9 is an enlarged view of a coated article in accordance with further embodiments; and

FIG. 10 is an enlarged view of a coated article in accordance with further embodiments.

## DETAILED DESCRIPTION

**[0026]** Major considerations in the application of coatings in certain applications include, but are not limited to, corrosion and fatigue concerns. That is, coatings must possess requisite corrosion resistance for the applications in which they are employed. In addition, an ideal coating would often be galvanically similar to the material of the substrate on which the coating is applied. This mitigates the potential for enhanced corrosion cells in the event of a partial loss or pitting of the coating. An ideal coating would also not adversely affect the expected fatigue life of the substrate being protected and in fact certain coatings, if they are well-adhered to the underlying substrate, can have a deleterious effect on fatigue life. For instance, a hard chromium coating (which is a widely used wear-resistant coating) on an aluminum substrate can degrade the life of the component due to the formation of cracks in the chromium. Such intrinsic cracking can then provide sites for fatigue crack propagation into and through the aluminum at a lower effective threshold than what would be present for uncoated aluminum. In such cases, the chromium coating not only reduces the life of the component but also may not even provide adequate corrosion resistance.

**[0027]** A situation where a hard coating actually increases cracking rates and propagation can be addressed by the provision of an interlayer coating that resists crack growth. An example of such a coating is taught in US Patent No. 7,854,966 which describes an interlayer coating having an elastic modulus which is lower than the substrate being protected and a top coating of cemented carbide material. While this coating addresses the problem of crack growth, the top coating is deposited via line-of-sight (LOS) processes and may be less effective or impossible to apply in non-line-of-sight (NLOS) cases.

**[0028]** With reference to FIGS. 1 and 2, as used herein, a LOS process refers to a coating deposition process in which the substrate 100 being coated has a clear LOS to a predefined location of a depositional source 101, such as a spray gun for a high velocity oxygen fuel (HVOF) process as shown in FIG. 1. By contrast, a NLOS process refers to a coating process in which at least a portion of the substrate 200 being coated lacks a clear LOS to a predefined location of what would be a depositional source 201 or is shadowed by another part or as a coating process that has an inherent LOS limitation where coating properties are significantly degraded beyond a certain deposition angle. That is, where the substrate 200 in FIG. 2 is formed to define a bore-hole 202 (blind, semi-blind or through), the substrate 200 may include a first surface 203 that has a clear LOS to the depositional source 201 and a second surface 204 (e.g., the interior facing surface of the bore-hole 202) that either lacks a clear LOS to the depositional source 201 or presents a case where the process has an inherent LOS limitation in which coating processes are significantly degraded beyond a certain depositional angle due to the relatively high length/diameter (L/D) ratio of the bore-hole 202.

**[0029]** For cases like the one shown in FIG. 2, a coating of the second surface 204 that is formed by depositional processes such as HVOF can have a characteristically low strain threshold that is effectively decreased even further due to the use of a LOS process in a NLOS situation (i.e., in what is effectively a NLOS process). Thus, a probability of a crack propagating into the second surface 204 may be substantially increased especially if a crack in the coating resulted in stress intensities in the second surface 204 that exceed threshold stress intensities in fatigue critical applications. Moreover, while this issue can be mitigated, the mitigating solutions are themselves problematic. For example, although compressive residual stresses which would resist crack propagation can be imparted to the second surface 204 by shot peening, laser shock peening, deep rolling, low plasticity burnishing, etc., these processes can add complexity and fabrication costs, are only marginally effective for NLOS cases and tend to lose effect at certain operational temperatures.

**[0030]** As a general matter, a LOS process could be defined as having an inherent LOS limitation where coating properties are significantly degraded beyond a certain deposition angle. Here, it is to be understood that LOS limitations vary by process such that a LOS process for certain deposition angles is a NLOS process for other deposition angles or two different processes can be regarded as LOS and NLOS processes, respectively, for a given deposition angle.

**[0031]** With reference to FIGS. 3-7, a non-line-of-sight (NLOS) coating process is provided that addresses the above-described issues with depositional coatings in NLOS cases.

**[0032]** As shown in FIG. 3, the NLOS coating process begins with the provision of a substrate 300 that has a first surface 301 and a second surface 302 which is transversely oriented with respect to the first surface 301. In accordance with embodiments, the substrate 300 may be formed to define a bore-hole 303 (blind, semi-blind or through) and the second surface 302 may be provided as an interior facing surface of that bore-hole 303. In any case, while the first surface 301 may have a LOS for depositional processing from a predefined location PL, the second surface 302 lacks a LOS for depositional processing from the predefined PL.

**[0033]** In accordance with embodiments, the bore-hole 303 may have a length to diameter (L/D) ratio of greater than 2 or, more particularly, greater than 2.75. Thus, it is to be understood that LOS processes could not be easily or reliably employed to form a coating along an entirety of the second surface 302.

**[0034]** As shown in FIG. 4, a crack-resistant interlayer coating 400 may be applied to (or be otherwise proximate to) at least the second surface 302 by electroplating, electroless plating or another similar process. In accordance with embodiments, where the second surface 302 includes at least one or more of stainless steels, carbon steels, titanium alloys, nickel based superalloys, aluminum alloys and magnesium alloys, the crack-resistant interlayer coating 400 may have a low elastic modulus and/or a high fracture toughness as compared to the second surface 302 and/or may be provided as a porous layer. In any case, the crack-resistant interlayer coating 400 may include at least one of zinc (Zn), tin (Sn), tin-zinc (Sn-Zn), silver (Ag), indium (In), bismuth (Bi), gold (Au), lead (Pb), cadmium (Cd) and aluminum (Al).

**[0035]** As used herein, the term "electroplating" refers to a process that uses electric current to reduce dissolved metal cations so that they form a thin coherent metal coating on an electrode or, in this case, at least the second surface 302 of the substrate 300. Electroplating or electrodeposition is primarily used to change the surface properties of an object but may also be used to build up surface thicknesses or to form objects by electroforming. As used herein, the term "electroless plating," which is also known as chemical or auto-catalytic plating, is a non-galvanic plating method that involves several simultaneous chemical reactions in an aqueous solution, which occur without the use of external electrical power. A main difference between electroless plating and electroplating arises from the fact that electroless plating does not use external electrical power.

**[0036]** Although the illustration of FIG. 4 indicates that the crack-resistant interlayer coating 400 is only formed on the second surface 302, it is to be understood that this is not required and is shown only for clarity and brevity. In fact, the crack-resistant interlayer coating 400 can be formed on the first surface 301 as well by the electroplating process or by any other LOS or NLOS process. The following description will nevertheless relate only to the case of the crack-resistant interlayer coating 400 (and subsequent coating layers) being formed on only the second surface 302.

**[0037]** As shown in FIG. 5, once the crack-resistant interlayer coating 400 is applied to at least the second surface 302, a wear-resistant coating 500 may be applied to a second or exterior interface 402 of the crack-resistant interlayer coating 400 by electrolytic or electroless plating (e.g., nickel plating). In accordance with embodiments, the wear-resistant coating 500 may include at least one of chromium (Cr), cobalt phosphorus (Co-P), nickel tungsten (Ni-W), nickel boron (Ni-B) and nickel phosphorus (Ni-P) and, in some cases as shown in FIG. 6, a codeposited particulate additive 501 such as boron nitride (BN) or cubic BN, diamonds, chromium carbide ($Cr_3C_2$, silicon carbide (SiC), etc. In accordance with further embodiments, additional materials of the wear-resistant coating 500 may be provided for at least some degree of wear resistant and may include nickel (Ni), cobalt (Co), nickel cobalt (Ni-Co), etc.

**[0038]** As shown in FIG. 7, the NLOS process may further include interposing a corrosion-resistant coating 700 between the second surface 302 and a first or interior interface 401 of the crack-resistant interlayer coating 400 which faces the second surface 302 (and/or interposing the corrosion-resistant coating 700 between the second or exterior interface 402 of the crack-resistant interlayer coating 400 and the wear-resistant coating 500 as shown in FIG. 10 to be discussed below). Where such corrosion-resistant coating 700 is interposed between the second surface 302 of the substrate 300 and the first or interior interface 401 of the crack-resistant interlayer coating 400, the corrosion-resistant coating 700 may include at least one of zinc (Zn), tin (Sn) and tin-zinc (Zn-Sn). Where the corrosion resistant coating 700 is interposed between the second or exterior interface 402 of the crack-resistant interlayer coating 400 and the wear-resistant coating 500, the corrosion-resistant coating 700 may include at least one of nickel phosphorous (Ni-P), nickel (Ni) and zinc nickel (Zn-Ni). While zinc (Zn), tin (Sn) and tin-zinc (Zn-Sn) could also be applied on the second or exterior interface 402, they are typically better suited to be applied directly to the second surface 302 as a corrosion-resistant coating.

**[0039]** With continued reference to FIG. 7 and with additional reference back to FIGS. 5 and 6, cracks that are present or grown in the wear-resistant coating 500 are resisted and turned back by the crack-resistant interlayer coating 400. Thus, cracks in the wear-resistant coating 500 do not propagate to the second surface 302. Thus, cracking of the second surface 302 and the substrate 300 as a whole is eliminated or at least substantially reduced.

**[0040]** With reference to FIGS. 8 and 9, a coated article 800 is provided as a result of the coating processes described hereinabove. The coated article 800 includes a substrate 801 that has a first surface and a second surface 803 which is transversely oriented with respect to the first surface. The first surface has a LOS for depositional processing from a predefined location and the second surface 803 lacks a LOS for depositional processing from the predefined location. The coated article 800 further includes a crack-resistant interlayer coating 804, which includes a first or interior interface 8041 and a second or exterior interface 8042 and is electroplated to at least the second surface 803, and a wear-resistant coating 805. The wear-resistant coating 805 may be electrolyticly or electrolessly plated to the second interface 8042 of the crack-resistant interlayer coating 804. As shown in FIG. 9, a corrosion-resistant coating 806 may be interposed between the second surface 803 of the substrate 801 and the first interface 8041 of the crack-resistant interlayer coating 804.

**[0041]** As noted above, with reference to FIG. 10, the corrosion-resistant coating 806 may be interposed between the second or exterior interface 8042 of the crack-resistant interlayer coating 804 and the wear-resistant coating 805.

**[0042]** While the embodiments of FIGS. 9 and 10 are drawn and explained separately, it is to be understood that additional embodiments exist in which the corrosion-resistant coating 806 is interposed between the second surface 803 of the substrate 801 and the first interface 8041 of the crack-resistant interlayer coating 804 and between the second or exterior interface 8042 of the crack-resistant interlayer coating 804 and the wear-resistant coating 805. Still further embodiments exist in which additional corrosion-resistant or wear-resistant coatings are provided on an exterior surface of the wear-resistant coating 805.

**[0043]** In any case, in the embodiments of FIGS. 8, 9 and 10, cracks may develop in the wear-resistant coating 805 during operational use of the coated article 800 or during the coating processes themselves. Such cracks may initiate proximate to or propagate toward the crack-resistant interlayer coating 804. In any case, the cracks are resisted or, in some cases, redirected along interfaces or turned away from the second surface 803 by the crack-resistant interlayer coating 804. Thus, the presence of the crack-resistant interlayer coating 804 serves to eliminate or substantially reduce cracking and other similar failures in the substrate 801 to thereby extend a lifetime of the coated article 800.

**[0044]** While the disclosure is provided in detail in connection with only a limited number of embodiments, it should be readily understood that the disclosure is not limited to such disclosed embodiments. Rather, the disclosure can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the disclosure. Additionally, while various embodiments of the disclosure have been described, it is to be understood that the exemplary embodiment(s) may include only some of the described exemplary aspects. Accordingly, the disclosure is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

Certain preferred embodiments of the present disclosure are as follows:

1. A non-line-of-sight (NLOS) coating process for a substrate having first and second transverse surfaces where the second surface lacks a LOS for depositional processing, the NLOS coating process comprising:

electroplating or electroless plating a crack-resistant interlayer coating to at least the second surface; and

applying a wear-resistant coating to the crack-resistant interlayer coating by electrolytic or electroless plating.

2. The NLOS coating process according to embodiment 1, wherein the substrate defines a bore-hole and the second surface is an interior facing surface of the bore-hole.

3. The NLOS coating process according to embodiment 1, wherein:

the substrate comprises at least one or more of stainless steels, carbon steels, titanium alloys, nickel based superalloys, aluminum alloys and magnesium alloys, and

the crack-resistant interlayer coating has a low elastic modulus and/or a high fracture toughness as compared to the substrate and is porous.

4. The NLOS coating process according to embodiment 1, wherein the crack-resistant interlayer coating comprises at least one of zinc (Zn), tin (Sn), tin-zinc (Sn-Zn), silver (Ag), indium (In), bismuth (Bi), gold (Au), lead (Pb), cadmium (Cd) and aluminum (Al).

5. The NLOS coating process according to embodiment 1, wherein the electrolytic or electroless plating comprises nickel plating.

6. The NLOS coating process according to embodiment 1, wherein:

the wear-resistant coating comprises at least one of chromium (Cr), cobalt phosphorus (Co-P), nickel tungsten (Ni-W), ni (Ni), cobalt (Co), nickel cobalt (Ni-Co), nickel boron (Ni-B) and nickel phosphorus (Ni-P), and

the wear-resistant coating further comprises boron nitride (BN) or cubic BN, diamonds, chromium carbide ($Cr_3C_2$) and silicon carbide (SiC).

7. The NLOS coating process according to embodiment 1, further comprising at least one of:

interposing a corrosion-resistant coating between the substrate and the crack-resistant interlayer coating; and

interposing the corrosion-resistant coating between the crack-resistant interlayer coating and the wear-resistant coating.

8. The NLOS coating process according to embodiment 7, wherein:

where the corrosion-resistant coating is interposed between the substrate and the crack-resistant interlayer coating, the corrosion resistant coating comprises at least one of zinc (Zn), tin (Sn) and tin-zinc (Zn-Sn), and

where the corrosion-resistant coating is interposed between the crack-resistant interlayer coating and the wear-resistant coating, the corrosion-resistant coating comprises at least one of nickel phosphorous (Ni-P), nickel (Ni), Zn, Sn, Sn-Zn and zinc nickel (Zn-Ni).

9. A coated article, comprising:

a substrate having first and second transverse surfaces, the second surface lacking a LOS for depositional processing;

a crack-resistant interlayer coating which is electroplated or electroless plated to at least the second surface; and

a wear-resistant coating which is electrolyticly or electrolessly plated to the crack-resistant interlayer coating.

10. The coated article according to embodiment 9, wherein the substrate defines a bore-hole and the second surface is an interior facing surface of the bore-hole.

11. The coated article according to embodiment 9, wherein:

the substrate comprises at least one or more of stainless steels, carbon steels, titanium alloys, nickel based superalloys, aluminum alloys and magnesium alloys, and

the crack-resistant interlayer coating has a low elastic modulus and/or a high fracture toughness as compared to the substrate and is porous.

12. The coated article according to embodiment 9, wherein the crack-resistant interlayer coating comprises at least one of zinc (Zn), tin (Sn), tin-zinc (Sn-Zn), silver (Ag), indium (In), bismuth (Bi), gold (Au), lead (Pb), cadmium (Cd) and aluminum (Al).

13. The coated article according to embodiment 9, wherein:

the wear-resistant coating comprises at least one of chromium (Cr), cobalt phosphorus (Co-P), nickel tungsten (Ni-W), ni (Ni), cobalt (Co), nickel cobalt (Ni-Co), nickel boron (Ni-B) and nickel phosphorus (Ni-P), and

the wear-resistant coating further comprises boron nitride (BN) or cubic BN, diamonds, chromium carbide ($Cr_3C_2$) and silicon carbide (SiC).

14. The coated article according to embodiment 9, further comprising at least one of:

a corrosion-resistant coating interposed between the substrate and the crack-resistant interlayer coating; and

the corrosion-resistant coating interposed between the crack-resistant interlayer coating and the wear-resistant coating.

15. The coated article according to embodiment 14, wherein:

where the corrosion-resistant coating is interposed between the substrate and the crack-resistant interlayer coating, the corrosion resistant coating comprises at least one of zinc (Zn), tin (Sn) and tin-zinc (Zn-Sn), and

where the corrosion-resistant coating is interposed between the crack-resistant interlayer coating and the wear-resistant coating, the corrosion-resistant coating comprises at least one of nickel phosphorous (Ni-P), nickel (Ni), Zn, Sn, Sn-Zn and zinc nickel (Zn-Ni).

## Claims

**1.** A non-line-of-sight (NLOS) coating process for a substrate having first and second transverse surfaces where the second surface lacks a LOS for depositional processing, the NLOS coating process comprising:

electroplating or electroless plating a crack-resistant interlayer coating to at least the second surface; and
applying a wear-resistant coating to the crack-resistant interlayer coating by electrolytic or electroless plating.

**2.** The NLOS coating process according to claim 1, wherein the substrate defines a bore-hole and the second surface is an interior facing surface of the bore-hole.

**3.** The NLOS coating process according to claim 1 or claim 2, wherein:

the substrate comprises at least one or more of stainless steels, carbon steels, titanium alloys, nickel based superalloys, aluminum alloys and magnesium alloys, and
the crack-resistant interlayer coating has a low elastic modulus and/or a high fracture toughness as compared to the substrate and is preferably porous.

**4.** The NLOS coating process according to any preceding claim, wherein the crack-resistant interlayer coating comprises at least one of zinc (Zn), tin (Sn), tin-zinc (Sn-Zn), silver (Ag), indium (In), bismuth (Bi), gold (Au), lead (Pb), cadmium (Cd) and aluminum (Al).

**5.** The NLOS coating process according to any preceding claim, wherein the electrolytic or electroless plating comprises nickel plating.

**6.** The NLOS coating process according to any preceding claim, wherein:

the wear-resistant coating comprises at least one of chromium (Cr), cobalt phosphorus (Co-P), nickel tungsten (Ni-W), nickel (Ni), cobalt (Co), nickel cobalt (Ni-Co), nickel boron (Ni-B) and nickel phosphorus (Ni-P), and
the wear-resistant coating further comprises boron nitride (BN) or cubic BN, diamonds, chromium carbide ($Cr_3C_2$) and silicon carbide (SiC).

**7.** The NLOS coating process according to any preceding claim, further comprising at least one of:

interposing a corrosion-resistant coating between the substrate and the crack-resistant interlayer coating; and
interposing the corrosion-resistant coating between the crack-resistant interlayer coating and the wear-resistant coating.

**8.** The NLOS coating process according to claim 7, wherein:

where the corrosion-resistant coating is interposed between the substrate and the crack-resistant interlayer coating, the corrosion resistant coating comprises at least one of zinc (Zn), tin (Sn) and tin-zinc (Zn-Sn), and
where the corrosion-resistant coating is interposed between the crack-resistant interlayer coating and the wear-resistant coating, the corrosion-resistant coating comprises at least one of nickel phosphorous (Ni-P), nickel (Ni), Zn, Sn, Sn-Zn and zinc nickel (Zn-Ni).

**9.** A coated article, comprising:

a substrate having first and second transverse surfaces, the second surface lacking a LOS for depositional processing;
a crack-resistant interlayer coating which is electroplated or electroless plated to at least the second surface; and
a wear-resistant coating which is electrolytically or electrolessly plated to the crack-resistant interlayer coating.

**10.** The coated article according to claim 9, wherein the substrate defines a bore-hole and the second surface is an interior facing surface of the bore-hole.

**11.** The coated article according to claim 9 or claim 10, wherein:

the substrate comprises at least one or more of stainless steels, carbon steels, titanium alloys, nickel based superalloys, aluminum alloys and magnesium alloys, and
the crack-resistant interlayer coating has a low elastic modulus and/or a high fracture toughness as compared to the substrate and is preferably porous.

**12.** The coated article according to any one of claims 9 - 11, wherein the crack-resistant interlayer coating comprises at least one of zinc (Zn), tin (Sn), tin-zinc (Sn-Zn), silver (Ag), indium (In), bismuth (Bi), gold (Au), lead (Pb), cadmium (Cd) and aluminum (Al).

**13.** The coated article according to any one of claims 9 - 12, wherein:

the wear-resistant coating comprises at least one of chromium (Cr), cobalt phosphorus (Co-P), nickel tungsten (Ni-W), nickel (Ni), cobalt (Co), nickel cobalt (Ni-Co), nickel boron (Ni-B) and nickel phosphorus (Ni-P), and
the wear-resistant coating further comprises boron nitride (BN) or cubic BN, diamonds, chromium carbide ($Cr_3C_2$) and silicon carbide (SiC).

**14.** The coated article according to any one of claims 9 - 13, further comprising at least one of:

a corrosion-resistant coating interposed between the substrate and the crack-resistant interlayer coating; and
the corrosion-resistant coating interposed between the crack-resistant interlayer coating and the wear-resistant coating.

**15.** The coated article according to claim 14, wherein:

where the corrosion-resistant coating is interposed between the substrate and the crack-resistant interlayer coating, the corrosion resistant coating comprises at least one of zinc (Zn), tin (Sn) and tin-zinc (Zn-Sn), and
where the corrosion-resistant coating is interposed between the crack-resistant interlayer coating and the wear-resistant coating, the corrosion-resistant coating comprises at least one of nickel phosphorous (Ni-P), nickel (Ni), Zn, Sn, Sn-Zn and zinc nickel (Zn-Ni).

FIG. 1

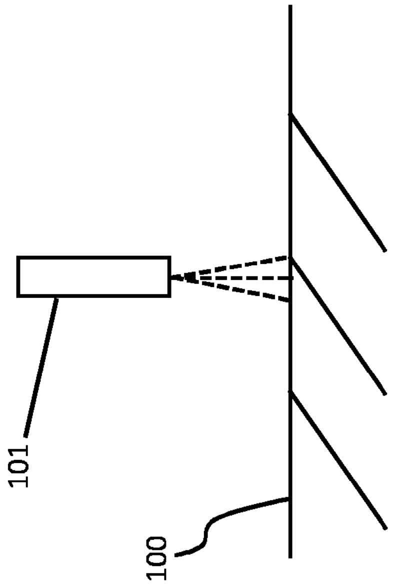



FIG. 2

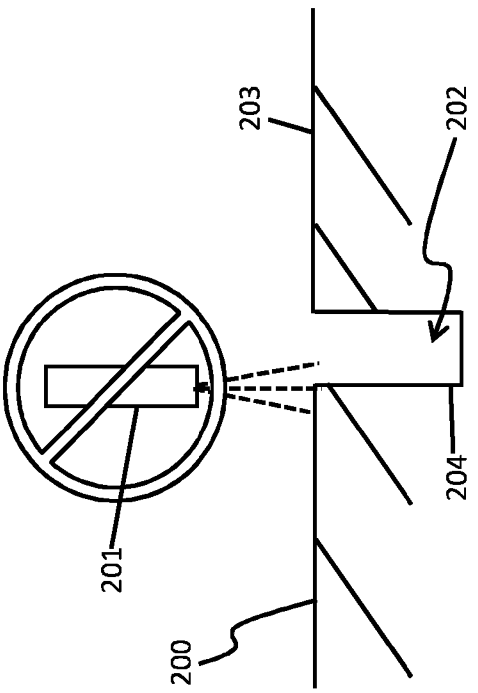



FIG. 3

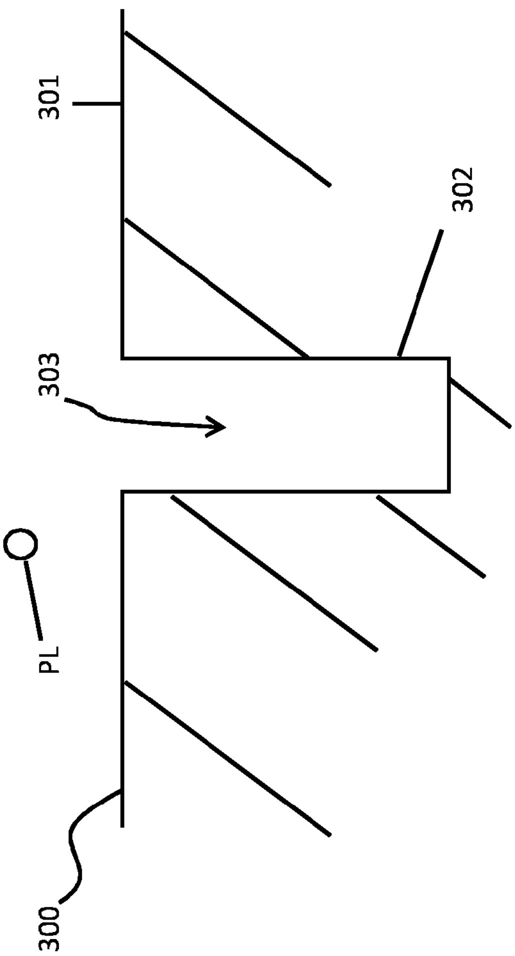


FIG. 4

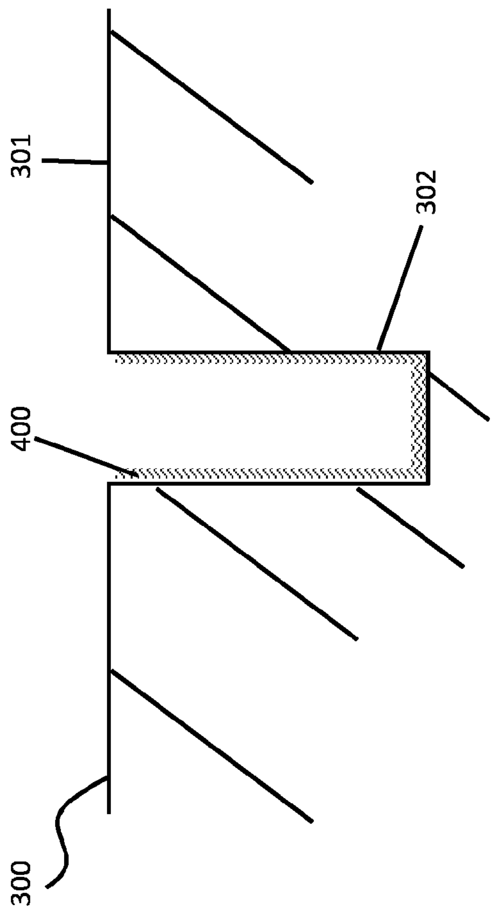



FIG. 5

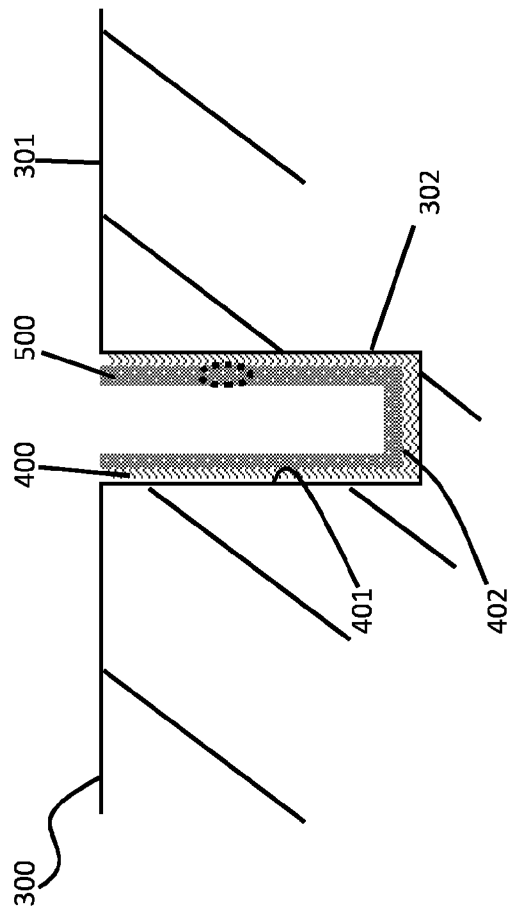


FIG. 6

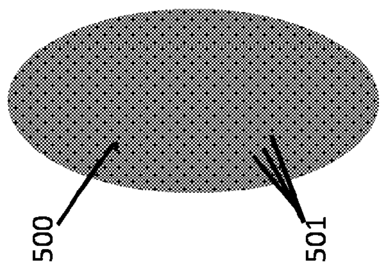



FIG. 7

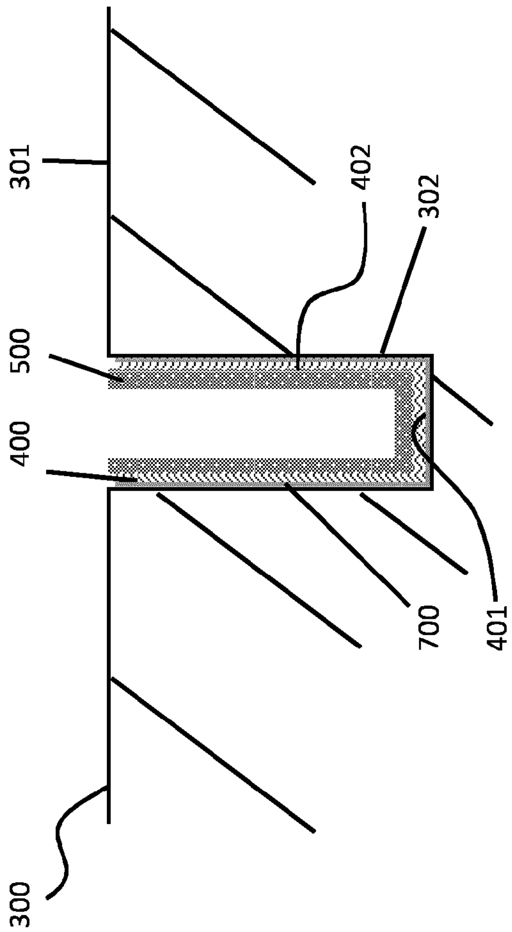


FIG. 9

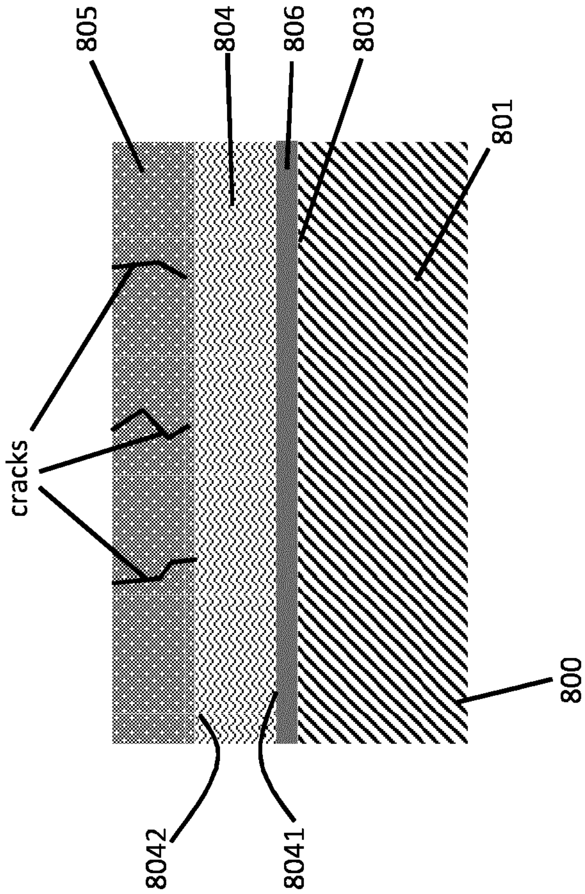



FIG. 8

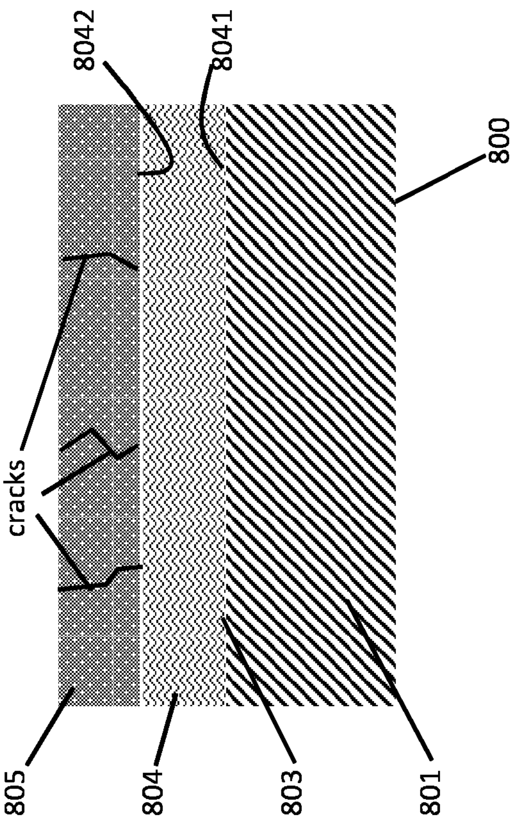
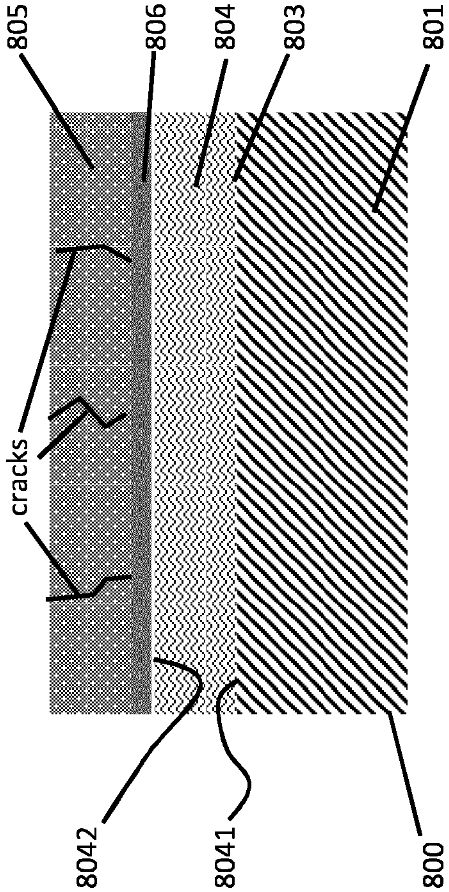



FIG. 10



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Application Number
EP 18 16 5956

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C25D
C23C

The present search report has been drawn up for all claims

1

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| The Hague | 31 August 2018 | Le Hervet, Morgan |

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