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(54) **COATINGS FOR USE IN FUEL SYSTEM COMPONENTS**

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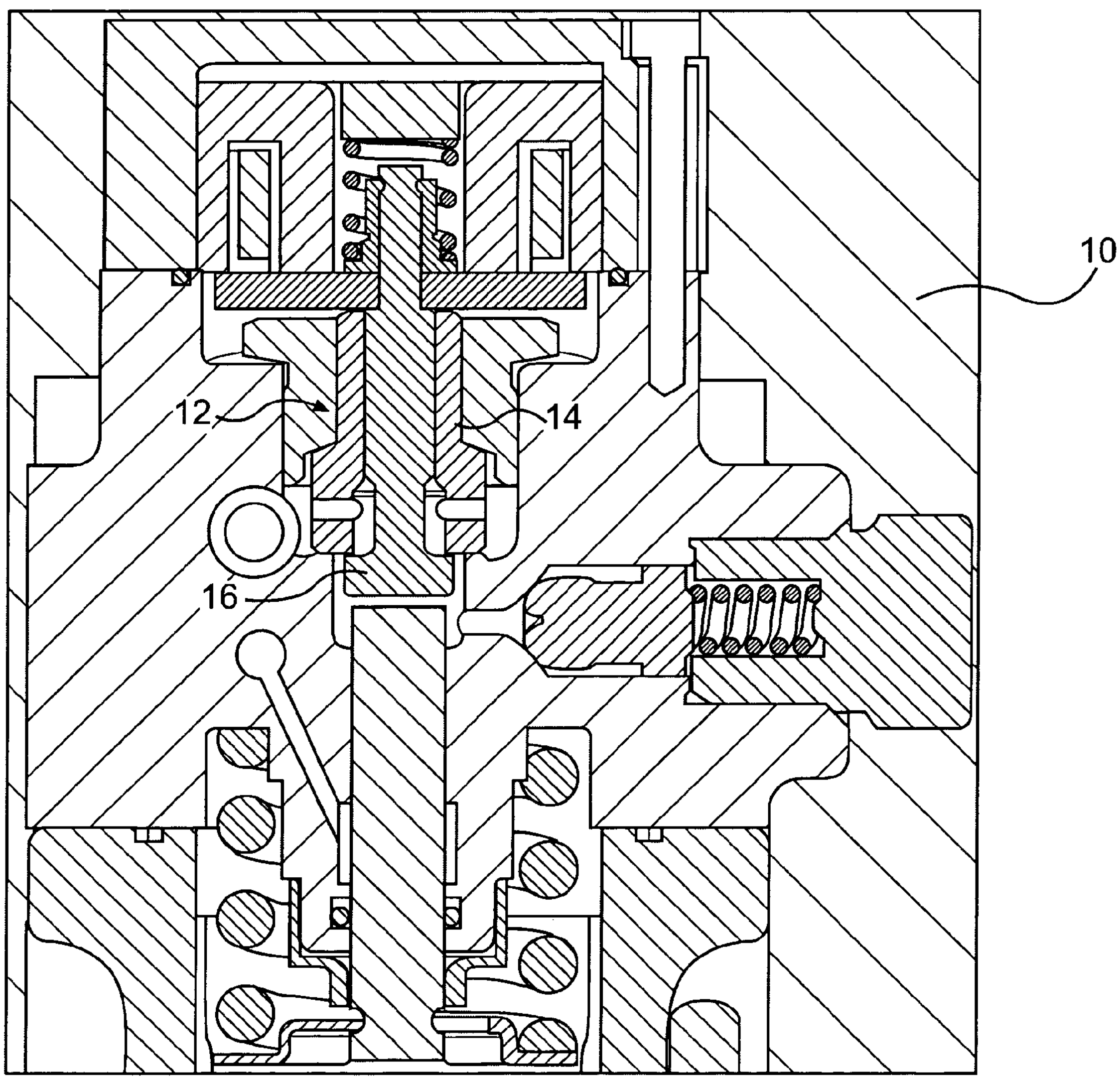
(57) **ABSTRACT**

A fuel pump assembly is provided. The assembly includes a first pump component having a first substrate and a first coating disposed on the first substrate. The assembly further includes at least one second pump component having a second substrate and a second coating disposed on the second substrate, wherein the first and second coatings are configured to repeatedly impact one another. In addition, the first coating may be selected from the group consisting of metal nitrides and diamond like carbon, and the second coating may be selected from the group consisting of metal nitrides and diamond like carbon.



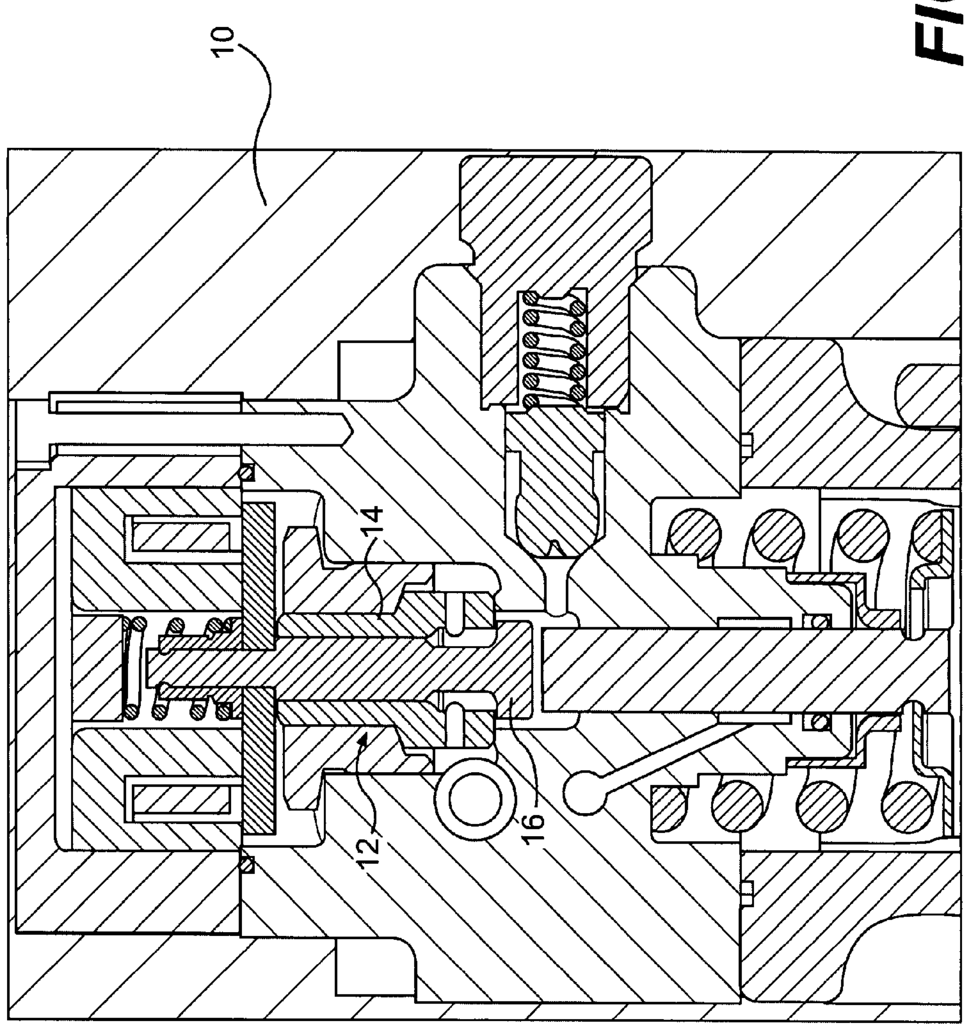


FIG. 1

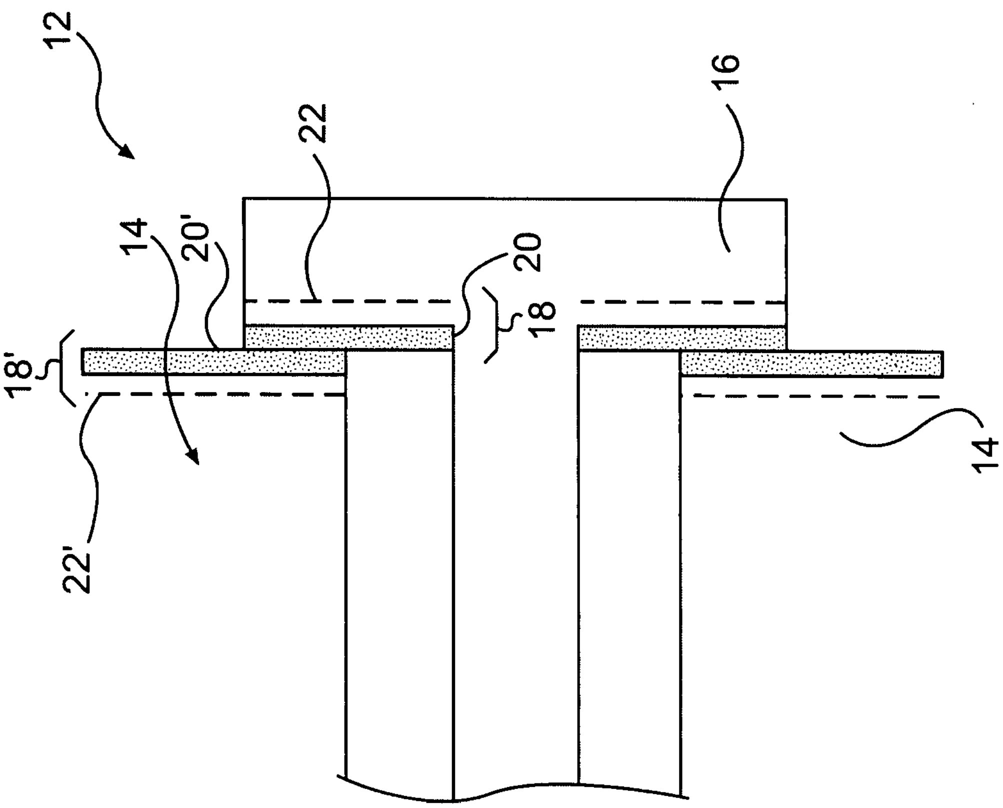


FIG. 2

COATINGS FOR USE IN FUEL SYSTEM COMPONENTS

[0001] This application claims benefit of U.S. Provisional Application No. 60/877,143, filed Dec. 26, 2006, the contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] This disclosure relates to fuel system components and more particularly to coatings or surface treatments for fuel pump components.

BACKGROUND

[0003] Many internal combustion engines, whether compression ignition or spark ignition engines, are provided with fuel systems to satisfy the need for precise and reliable fuel delivery into the combustion chamber of the engine. Such precision and reliability is necessary to address the goals of increasing fuel efficiency, maximizing power output, and controlling undesirable by-products of combustion. Generally, fuel systems will include a fuel pump and one or more fuel injectors. The fuel pump will supply fuel to the injectors, which will subsequently provide precision control of the fuel supply and timing to engine cylinders.

[0004] Traditionally, hard coatings are applied to components of fuel systems to reduce wear. For example, where opposing parts contact one another, a wear resistant coating may be used to reduce wear between the components. However, generally, it is believed that it is desirable to apply a coating to only one surface of opposing parts. Further, the other opposing surface is often produced from a bare metal (e.g. steel substrate) or other material that is softer than the hard coating applied to the opposing surface. In this way, the uncoated bare metal may be polished, and the overall wear rate will be reduced.

[0005] One prior art fuel system component that includes hard coatings on two opposing surfaces is disclosed in U.S. Pat. No. 6,062,499, which issued to Nakamura et. al on May 16, 2000 (hereinafter the '499 patent). The '499 patent provides an injector with a conduit bearing surface and a movable core in contact therewith. Both the bearing surface and moveable core are coated with high-hardness materials such as chrome or titanium.

[0006] Although the coatings and injector of the '499 patent may provide suitable wear resistance for some applications, the coatings of the '499 patent may have several drawbacks. For example, the coatings of the '499 patent may not provide suitable impact wear resistance, and therefore, may not be suitable for use on opposing surfaces of fuel pump components that may produce impact wear. In addition, these coatings may wear at an unacceptably high rate in the presence of newer fuels. Therefore, these coatings may fail when used under some conditions, thereby causing the fuel system component to leak or lose pressure.

[0007] The disclosed coatings aid in overcoming one or more of the short comings of the prior art fuel system coating.

SUMMARY OF THE INVENTION

[0008] A first aspect of the present disclosure includes a fuel pump assembly. The assembly includes a first fuel pump component having a first substrate and a first coating disposed on the first substrate. The assembly further includes at least one second fuel pump component having a second substrate and a second coating disposed on the second substrate, wherein the first and second coatings are configured to repeatedly impact one another. In addition, the first coating may be selected from the group consisting of metal nitrides and diamond like carbon, and the second coating may be selected from the group consisting of metal nitrides and diamond like carbon

[0009] A second aspect of the present disclosure includes a method of producing a fuel pump assembly. The method may include selecting a first fuel pump component substrate and a second fuel pump component substrate. The method may further include producing a first coating on the first substrate and a second coating on the second substrate, and assembling the fuel pump such that the first and second coatings are configured to repeatedly impact one another during operation of the fuel pump. The first coating may be selected from the group consisting of metal nitrides and diamond like carbon, and the second coating may be selected from the group consisting of metal nitrides and diamond like carbon

[0010] A third aspect of the present disclosure includes a method of controlling wear in a fuel pump assembly, wherein the fuel pump assembly comprises a first fuel pump component substrate, a second fuel pump component substrate, a first coating on the first substrate, and a second coating on the second substrate. The first coating may be selected from the group consisting of metal nitrides and diamond like carbon, and the second coating may be selected from the group consisting of metal nitrides and diamond like carbon. The method includes operating the fuel pump assembly such that the first coating repeatedly impacts the second coating. The method may further include supplying fuel to the fuel pump assembly.

[0011] A fourth aspect of the present disclosure includes an assembly having two or more components configured to repeatedly impact one another. The assembly may comprise a first component having a first substrate and a first coating disposed on the first substrate. The assembly may further comprise at least one second component having a second substrate and a second coating disposed on the second substrate. The first and second coatings may be configured to repeatedly impact one another. Further, the first coating may be selected from the group consisting of metal nitrides and diamond like carbon, and the second coating may be selected from the group consisting of metal nitrides and diamond like carbon.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** illustrates a fuel pump assembly including a nail valve, according to an exemplary disclosed embodiment.

[0013] FIG. **2** is a cross-sectional view of two components of a fuel pump including coatings on opposing surfaces of the fuel pump, according to an exemplary embodiment.

DETAILED DESCRIPTION

[0014] FIG. **1** illustrates a fuel pump assembly **10** including a nail valve assembly **12**, according to an exemplary disclosed embodiment. As shown, nail valve assembly **12** includes a moving valve **16** and valve body **14**. Further, as shown, valve **16** engages valve body **14** to prevent fuel flow through pump assembly **10**. During operation, valve **16** may repeatedly and forcefully engage valve body **14**, causing repeated impact between opposing surfaces of valve **16** and valve body **14**. To prevent wear of mating surfaces of valve **16** and valve body

14, these surfaces may be produced from or include a coating that will provide resistance to impact and/or sliding wear.

[0015] FIG. **2** is a cross-sectional view of a nail valve **12** of a fuel pump assembly **10** including coatings **18**, **18'** on opposing surfaces of the fuel pump assembly components (valve **16** and valve body **14**), according to an exemplary embodiment. As shown, valve **16** and valve body **14** can include primary coating layers **20**, **20'** disposed on substrate materials of valve **16** and valve body **14**. In some embodiments, coating layers **20**, **20'** can be produced from hard, wear-resistant materials. Further, in some embodiments, coatings **18**, **18'** can optionally include a bond layer **22**, **22'** between the primary coatings **20**, **20'** and substrates.

[0016] As noted, coatings **18**, **18'** may include hard, wear resistant materials. Such materials may be selected to prevent wear of machine components that are configured to repeatedly engage one another to produce impact between the two surfaces. For example, suitable primary coating materials **20**, **20'** can be selected from various metal nitrides and diamond like carbons (DLC). For example, suitable metal nitrides can include chromium nitride, zirconium nitride, molybdenum nitride, titanium-carbon-nitride, or zirconium-carbon-nitride, and suitable diamond-like carbon materials can include titanium containing diamond like carbon (DLC), tungsten-DLC, or chromium-DLC. In addition, suitable metal carbon materials, including tungsten-carbide containing carbon may be selected. Where tungsten-carbide containing carbon is used the tungsten content may be graded, and thus may range at any various points in a layer between about 0% to about 100% by weight, or between about 15% and about 30% by weight.

[0017] In some embodiments, coating **18** on the moving valve component **16** may include the same or a similar material used to produce coating **18'** on the opposing surface of valve body **14**. For example, in one embodiment, coating **18** and coating **18'** will both include a metal nitride or both include a DLC, as described above. Further, in some embodiments, coating **18** and coating **18'** will both include chromium nitride.

[0018] As noted, depending on the intended application and environment of the coated fuel pump assembly **12**, a bond layer **22**, **22'** may be applied to the substrate before application of primary coatings **20**, **20'**. For example, suitable bond layers may include a layer of chromium or other suitable metal layer to the substrate of valve **16** and valve body **14** to provide improved adhesion of the primary coating **20**, **20'**. If used, the optional bond layer material can be applied using a vapor deposition process to yield bond layer **22**, **22'** having a thickness of generally between about 0.05 microns and about 0.5 microns. Further, the thickness of coating **18**, **18'** on valve **16** and valve body should be fairly uniform as measured on a sample of the fuel pump components by the Ball Crater Test at a plurality of locations on the valve **16** and/or valve body **14**. Alternatively one can demonstrate uniform coating thickness through scanning electron microscopy measurements on a sample of selected cross sections of the fuel pump components, or through the use of X-ray fluorescence.

[0019] Primary coating **20**, **20'** can have a range of suitable thicknesses. For example, primary coating **20**, **20'** may generally have a thickness no greater than about 5.0 microns, and may generally be between about 0.5 microns and about 1.7 microns, or between about 0.5 microns and about 1.0 microns.

[0020] Further, bond layers **22**, **22'** can have a range of suitable thicknesses. For example, bond layers **20**, **20'** generally will have a thickness no greater than about 1.0 micron, and in some embodiments, the bond layer thickness will be between about 0.1 microns and about 1.0 micron, between about 0.1 microns and about 0.3 microns, or between about 0.05 microns and about 0.5 microns.

[0021] Control of some or all of the physical properties of coatings **18**, **18'** and coated component substrates **14**, **16** other than thickness may also be important to producing a highly reliable and cost effective component. For example, coating adhesion, coating hardness, substrate hardness, surface texture, and frictional coefficients are some of the physical properties that may be monitored and controlled to produce desired coatings. Although different applications may demand different physical properties, various vapor deposition processes may be used to produce suitable coatings.

[0022] To produce suitable coatings, primary coatings **20**, **20'** should be generally free of surface defects and have specified surface texture ratings or surface texture measurements dependent on the intended use of the component. Surface defects are generally observed on coated samples through the observation of multiple points on the surface of samples at about a one hundred times magnification factor. The surface observations are generally compared to various classification standards to ensure the coatings are substantially free from surface defects as opposed to pin holes and substrate defects.

[0023] In addition, applied coatings **18**, **18'** may be selected to adhere to selected component substrate materials. Coating adhesion can be assessed for a given population of fuel pump components **14**, **16**, for example, by using standard hardness tests (e.g. Rockwell C HDNS measurements). The impact locations on the surface can be observed and generally compared to various adhesion classification standards based on the size and amount of cracks present and the flaking of the coatings.

[0024] As noted, a variety of deposition techniques may be used to produce suitable coatings **18**, **18'**. For example, suitable deposition processes can include physical vapor deposition (e.g. sputtering), chemical vapor deposition (CVD), and arc vapor deposition. Further, hybrid PVD/CVD processes may be used.

[0025] The desired coating process can be selected based on a number of factors, including, for example, cost, speed of production, and control of coating composition and structure. Further, the coating production process may be selected based on the type of substrate material selected for valve **16** and valve body **14**. For example, some substrates may be affected by elevated temperatures, and a coating process may be selected that requires temperatures that will minimize adverse effects of the process on selected substrates. For example, arc-vapor or sputtering processes may be selected to produce chromium nitride coatings, and suitable processes may be selected to maintain temperatures below 250° C.

[0026] Prior to coating, selected substrates may be cleaned, degreased, and/or prepared to produce a desired surface texture or polish. The cleaning and preparation of the substrates can be accomplished by conventional methods such as degreasing, grit blasting, etching, and chemically assisted vibratory techniques. Further, surface finishing operations performed prior to the coating application can include a grinding process to obtain a highly smooth surface, ultrasonic cleaning with an alkaline solution, and ion-etching of the substrate surface using argon. In addition, heat treatment operations specified for selected substrates can be performed prior to deposition of selected coatings.

[0027] A variety of suitable substrates may be selected. For example, various steels may be used depending on desired physical demands, cost, machinability, and/or bonding with coatings **18**, **18'**. Suitable substrates can include, for example low-alloy steels, tool steel, 51200 steel, and or any other suitable steel. Further other substrate materials may be selected as long as such materials bond suitably with selected coatings.

[0028] It has been discovered that the disclosed coatings can provide good wear resistance when subject to repeated impact and/or sliding wear, even in the presence of one or more of the variety of fuels flowing through fuel pump assembly **10**. A variety of suitable fuels may be selected, including various common diesel fuels and newer, low-lubricity or biodiesels. Further, many current machine components have been found to have high wear rates when subject to impact and/or sliding wear in the presence of certain hydrocarbon fuels, such as various low-lubricity fuels and/or low-sulfur fuels. The disclosed coatings have been found to produce good wear resistance when subject to repeated impact even in the presence of these fuels. For example, suitable fuels that may be used with the disclosed fuel pump assembly components as coated with the disclosed coatings can include ASTM D975 Grade 2D diesel, Toyu fuel, low-sulfur fuel, K1 fuel, and JP8 fuel, as well as other traditional fuels. Further, the disclosed coatings may also be used with fuels containing various additives, including Caterpillar 2564968 fuel additive, methyl soyate (10-30% by volume), rapeseed methyl ester, and reclaimed cooking oil. For example, selected fuel and additive combinations can include Toyu with at least about 10% by volume methyl soyate, or Toyu with at least about 20% by volume methyl soyate. Further, each of the disclosed additives may be combined with the disclosed fuels for use with selected coatings.

[0029] Finally, it should be noted that although the disclosed coatings are described for use with valve **16** and valve body **14**, the disclosed coatings may be used with any machine components that are subject to repeated impact and/or sliding engagement. Further, such coatings may be used with any machine components subject to these forms of wear, in the presence of various hydrocarbon fuels and/or fuel additives. For example, such components can include any valves or other components used in fuel pumps, fuel injectors, and/or other engine components that may be subject to wear.

INDUSTRIAL APPLICABILITY

[0030] The present disclosure provides coatings that produce low wear rates. The disclosed coatings may be used in any machine parts that are subject to repeated impact and/or sliding engagement.

[0031] The disclosed coatings can be applied to opposing surfaces of fuel pump assembly valves or other components that repeatedly engage one another in the presence of various fuels. The use of the disclosed component coatings in such fuel system applications provides low wear rates, and consequently, reduced fuel system failure. Using the coatings of the present disclosure on opposing surfaces can provide low component wear rates in the presence of convention engine fuels, but also in the presence of alternative fuels such as low lubricity Caterpillar fuel, biodiesels, Toyu fuel, JP8, and K1 fuel. Further, the improved wear rates can be achieved with the addition of various fuel additives such as methyl soyate, reconstituted cooking oil, and rapeseed methyl ester.

[0032] From the foregoing, it should be appreciated that the present invention thus provides a coating or surface treatment for fuel system components such as fuel pumps and fuel injector valves. While the invention herein disclosed has been described by means of exemplary embodiments and processes associated therewith, numerous modifications and variations can be made thereto by those skilled in the art without departing from the scope of the invention as set forth in the claims or sacrificing all its material advantages.

1. A fuel pump assembly comprising:
- a first fuel pump component having a first substrate and a first coating disposed on the first substrate;
- at least one second fuel pump component having a second substrate and a second coating disposed on the second substrate, wherein the first and second coatings are configured to repeatedly impact one another; and
- wherein the first coating is selected from the group consisting of metal nitrides and diamond like carbon, and the second coating is selected from the group consisting of metal nitrides and diamond like carbon.

2. The fuel pump assembly of claim **42**, wherein the first component includes a nail valve and the second component includes a nail valve body.

3. The fuel pump assembly of claim **1**, wherein the first coating and second coating have a thickness range between about 0.5 microns and about 1.7 microns.

4. The fuel pump assembly of claim **1**, wherein the first coating and second coating have a thickness range between about 0.5 microns and about 1.0 microns.

5. The fuel pump assembly of claim **1**, wherein the first coating is selected from the group consisting of chromium nitride, zirconium nitride, molybdenum nitride, titanium-carbon-nitride, and zirconium-carbon-nitride.

6. The fuel pump assembly of claim **5**, wherein the second coating is selected from the group consisting of chromium nitride, zirconium nitride, molybdenum nitride, titanium-carbon-nitride, and zirconium-carbon-nitride.

7. The fuel pump assembly of claim **6**, wherein the first coating and the second coating include the same coating material.

8. The fuel pump assembly of claim **1**, wherein the first coating includes chromium nitride and the second coating includes chromium nitride.

9. The fuel pump assembly of claim **1**, wherein the first coating is selected from the group consisting of titanium containing diamond like carbon, chromium containing diamond like carbon, and tungsten containing diamond like carbon.

10. The fuel pump assembly of claim **9**, wherein the second coating is selected from the group consisting of titanium containing diamond like carbon, chromium containing diamond like carbon, and tungsten containing diamond like carbon.

11. The fuel pump assembly of claim **1**, wherein at least one of the first component and the second component further includes a bond layer between the substrate and the coating.

12. The fuel pump assembly of claim **11**, wherein the bond layer is a chromium layer having a thickness in the range of between about 0.05 microns and about 0.50 microns.

13. The fuel pump assembly of claim **1**, wherein the first component and the second component are adapted to control the flow of a fuel.

14. A method of producing a fuel system pump assembly, comprising:
selecting a first fuel system component substrate;
selecting a second fuel system component substrate;
producing a first coating on the first substrate and a second coating on the second substrate, wherein the first coating is selected from the group consisting of metal nitrides and diamond like carbon, and the second coating is selected from the group consisting of metal nitrides and diamond like carbon; and
assembling the fuel system assembly such that the first and second coatings are configured to repeatedly impact one another.

15. The method of claim **14**, wherein the first component substrate forms part of a nail valve and the second component substrate forms part of a nail valve body.

16. The method of claim **14**, wherein the first coating is selected from the group consisting of chromium nitride, zirconium nitride, molybdenum nitride, titanium-carbon-nitride, and zirconium-carbon-nitride.

17. The method of claim **16**, wherein the second coating is selected from the group consisting of chromium nitride, zirconium nitride, molybdenum nitride, titanium-carbon-nitride, and zirconium-carbon-nitride.

18. The method of claim **14**, wherein the first coating includes chromium nitride and the second coating includes chromium nitride.

19. The method of claim **14**, wherein the first coating is selected from the group consisting of titanium containing diamond like carbon, chromium containing diamond like carbon, and tungsten containing diamond like carbon.

20. The method of claim **14**, wherein the first coating and the second coating are produced using a physical vapor deposition process.

21. The method of claim **20**, wherein the physical vapor deposition process includes a sputtering process.

22. A method of controlling wear in a fuel pump assembly comprising a first fuel pump component substrate, a second fuel pump component substrate, a first coating on the first substrate, and a second coating on the second substrate, wherein the first coating is selected from the group consisting of metal nitrides and diamond like carbon and the second coating is selected from the group consisting of metal nitrides and diamond like carbon, the method comprising:
operating the fuel pump assembly such that the first coating repeatedly impacts the second coating; and
supplying fuel to the pump assembly.

23. The method of claim **22**, wherein the fuel includes Toyu fuel.

24. The method of claim **22**, wherein the fuel includes at least 10% by volume methyl soyate.

25. The method of claim **22**, wherein the fuel includes at least 20% by volume methyl soyate.

26. The method of claim **22**, wherein the fuel includes Toyu fuel and methyl soyate.

27. The method of claim **26**, wherein at least one of the first coating and the second coating includes chromium nitride.

28. The method of claim **27**, wherein the first coating and the second coating include chromium nitride.

29. The method of claim **22**, wherein at least one of the first coating and the second coating is selected from the group consisting of zirconium nitride, molybdenum nitride, titanium-carbon-nitride, zirconium-carbon-nitride, titanium containing diamond like carbon, chromium containing diamond like carbon, and tungsten containing diamond like carbon.

30. The method of claim **22**, wherein the fuel is selected from the group consisting of ASTM D975 Grade 2D diesel, low-sulfur fuel, K1 fuel, and JP8 fuel.

31. An assembly having two or more components configured to repeatedly impact one another, comprising:
a first component having a first substrate and a first coating disposed on the first substrate;
at least one second component having a second substrate and a second coating disposed on the second substrate, wherein the first and second coatings are configured to repeatedly impact one another; and
wherein the first coating is selected from the group consisting of metal nitrides and diamond like carbon, and the second coating is selected from the group consisting of metal nitrides and diamond like carbon.

32. The assembly of claim **31**, wherein the first coating and second coating have a thickness range between about 0.5 microns and about 1.7 microns.

33. The assembly of claim **31**, wherein the first coating is selected from the group consisting of chromium nitride, zirconium nitride, molybdenum nitride, titanium-carbon-nitride, and zirconium-carbon-nitride.

34. The assembly of claim **33**, wherein the second coating is selected from the group consisting of chromium nitride, zirconium nitride, molybdenum nitride, titanium-carbon-nitride, and zirconium-carbon-nitride.

35. The assembly of claim **34**, wherein the first coating and the second coating include the same coating material.

36. The assembly of claim **31**, wherein the first coating includes chromium nitride and the second coating includes chromium nitride.

37. The assembly of claim **31**, wherein the first coating is selected from the group consisting of titanium containing diamond like carbon, chromium containing diamond like carbon, and tungsten containing diamond like carbon.

38. The assembly of claim **37**, wherein the second coating is selected from the group consisting of titanium containing diamond like carbon, chromium containing diamond like carbon, and tungsten containing diamond like carbon.

39. The assembly of claim **31**, wherein at least one of the first component and the second component further includes a bond layer between the substrate and the coating.

40. The assembly of claim **39**, wherein the bond layer is a chromium layer having a thickness in the range of between about 0.05 microns and 0.50 microns.

41. The assembly of claim **31**, wherein the first component and the second component are adapted to control the flow of a fuel.

42. The method of claim **1**, wherein the fuel system assembly includes a fuel injector.

43. The method of claim **14**, wherein the fuel system assembly includes a fuel injector.

44. The method of claim **14**, wherein the fuel system assembly includes a fuel injector valve.

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