glass body 102. The low-friction coating 120 has an outer surface 122 and a glass body contacting surface 124 at the interface of the glass body 102 and the low-friction coating 120. The low-friction coating 120 may be bonded to the glass body 102 at the exterior surface 108.

[0070] In one embodiment, the coated glass container 100 is a pharmaceutical package. For example, the glass body 102 may be in the shape of a vial, ampoule, ampul, bottle, flask, phial, beaker, bucket, carafe, vat, syringe body, or the like. The coated glass container 100 may be used for containing any composition, and in one embodiment, may be used for containing a pharmaceutical composition. A pharmaceutical composition may include any chemical substance intended for use in the medical diagnosis, cure, treatment, or prevention of disease. Examples of pharmaceutical compositions include, but are not limited to, medicines, drugs, medications, medicaments, remedies, and the like. The pharmaceutical composition may be in the form of a liquid, solid, gel, suspension, powder, or the like.

[0071] Now referring to FIGS. 1 and 2, in one embodiment, the low-friction coating 120 comprises a bi-layered structure. FIG. 2 shows a cross section of a coated glass container 100, where the low-friction coating comprises a polymer layer 170 and a coupling agent layer 180. A polymer chemical composition may be contained in polymer layer 170 and a coupling agent may be contained in a coupling agent layer 180. The coupling agent layer 180 may be in direct contact with the exterior surface 108 of the glass container wall 104. The polymer layer 170 may be in direct contact with the coupling agent layer 180 and may form the outer surface 122 of the low-friction coating 120. In some embodiments the coupling agent layer 180 is bonded to the glass wall 104 and the polymer layer 170 is bonded to the coupling agent layer 180 at an interface 174. However, it should be understood that, in some embodiments, the low-friction coating 120 may not include a coupling agent, and the polymer chemical composition may be disposed in a polymer layer 170 in direct contact with the exterior surface 108 of the of the glass container wall 104. In another embodiment, the polymer chemical composition and coupling agent may be substantially mixed in a single layer. In some other embodiments, the polymer layer may be positioned over the coupling agent layer, meaning that the polymer layer 170 is in an outer layer relative to the coupling agent layer 180, and the glass wall 104. As used herein, a first layer positioned "over" a second layer

means that the first layer could be in direct contact with the second layer or separated from the second layer, such as with a third layer disposed between the first and second layers.

[0072] Referring now to FIG. 3, in one embodiment, the low-friction coating 120 may further comprise an interface layer 190 positioned between the coupling agent layer 180 and the polymer layer 170. The interface layer 190 may comprise one or more chemical compositions of the polymer layer 170 bound with one or more of the chemical compositions of the coupling agent layer 180. In this embodiment, the interface of the coupling agent layer and polymer layer forms an interface layer 190 where bonding occurs between the polymer chemical composition and the coupling agent. However, it should be understood that in some embodiments, there may be no appreciable layer at the interface of the coupling agent layer 180 and polymer layer 170 where the polymer and coupling agent are chemically bound to one another as described above with reference to FIG. 2.

[0073] The low-friction coating 120 applied to the glass body 102 may have a thickness of less than about 100 μm or even less than or equal to about 1 μm. In some embodiments, the thickness of the low-friction coating 120 may be less than or equal to about 100 nm thick. In other embodiments, the low-friction coating 120 may be less than about 90 nm thick, less than about 80 nm thick, less than about 70 nm thick, less than about 60 nm thick, less than about 50 nm, or even less than about 25 nm thick. In some embodiments, the low-friction coating 120 may not be of uniform thickness over the entirety of the glass body 102. For example, the coated glass container 100 may have a thicker low-friction coating 120 in some areas, due to the process of contacting the glass body 102 with one or more coating solutions that form the low-friction coating 120. In some embodiments, the low-friction coating 120 may have a non-uniform thickness. For example, the coating thickness may be varied over different regions of a coated glass container 100, which may promote protection ~~is~~in a selected region.

[0074] In embodiments which include at least two layers, such as the polymer layer 170, interface layer 190, and/or coupling agent layer 180, each layer may have a thickness of less than about 100 μm or even less than or equal to about 1 μm. In some embodiments, the thickness of each layer may be less than or equal to about 100 nm. In other embodiments,

composition and a "second" silane chemical composition are silanes having different chemical compositions. The first silane chemical composition may be an aromatic or an aliphatic chemical composition, may optionally comprise an amine moiety, and may optionally be an alkoxysilane. Similarly, the second silane chemical composition may be an aromatic or an aliphatic chemical composition, may optionally comprise an amine moiety, and may optionally be an alkoxysilane.

[0078] For example, in one embodiment, only one silane chemical composition is applied as the coupling agent. In such an embodiment, the coupling agent may comprise a silane chemical composition, hydrolysate thereof, or oligomer thereof.

[0079] In another embodiment, multiple silane chemical compositions may be applied as the coupling agent. In such an embodiment, the coupling agent may comprise at least one of (1) a mixture of the first silane chemical composition and a second silane chemical composition, and (2) a chemical composition formed from the oligomerization of at least the first silane chemical composition and the second silane chemical composition.

[0080] Referring to the embodiments described above, the first silane chemical composition, second silane chemical composition, or both, may be aromatic chemical compositions. As used herein, an aromatic chemical composition contains one or more six-carbon rings characteristic of the benzene series and related organic moieties. The aromatic silane chemical composition may be an alkoxysilane such as, but not limited to, a dialkoxysilane chemical composition, hydrolysate thereof, or oligomer thereof, or a trialkoxysilane chemical composition, hydrolysate thereof, or oligomer thereof. In some embodiments, the aromatic silane may comprise an amine moiety, and may be an alkoxysilane comprising an amine moiety. In another embodiment, the aromatic silane chemical composition may be an aromatic alkoxysilane chemical composition, an aromatic acyloxysilane chemical composition, an aromatic halogen silane chemical composition, or an aromatic aminosilane chemical composition. In another embodiment, the aromatic silane chemical composition may be selected from the group consisting of aminophenyl, 3-(m-aminophenoxy) propyl, N-phenylaminopropyl, or (chloromethy) phenyl substituted alkoxy, acyloxy, ~~hylogen~~halogen, or amino silanes. For example, the aromatic alkoxysilane may be, but is

not limited to, aminophenyltrimethoxy silane (sometimes referred to herein as "APhTMS"), aminophenyldimethoxy silane, aminophenyltriethoxy silane, aminophenyldiethoxy silane, 3-(m-aminophenoxy) propyltrimethoxy silane, 3-(m-aminophenoxy) propyldimethoxy silane, 3-(m-aminophenoxy) propyltriethoxy silane, 3-(m-aminophenoxy) propyldiethoxy silane, N-phenylaminopropyltrimethoxysilane, N-phenylaminopropyldimethoxysilane, N-phenylaminopropyltriethoxysilane, N-phenylaminopropyldiethoxysilane, hydrolysates thereof, or oligomerized chemical composition thereof. In an exemplary embodiment, the aromatic silane chemical composition may be aminophenyltrimethoxy silane.

[0081] Referring again to the embodiments described above, the first silane chemical composition, second silane chemical composition, or both, may be aliphatic chemical compositions. As used herein, an aliphatic chemical composition is non-aromatic, such as a chemical composition having an open chain structure, such as, but not limited to, alkanes, alkenes, and alkynes. For example, in some embodiments, the coupling agent may comprise a chemical composition that is an alkoxysilane and may be an aliphatic alkoxysilane such as, but not limited to, a dialkoxysilane chemical composition, a hydrolysate thereof, or an oligomer thereof, or a trialkoxysilane chemical composition, a hydrolysate thereof, or an oligomer thereof. In some embodiments, the aliphatic silane may comprise an amine moiety, and may be an alkoxysilane comprising an amine moiety, such as an aminoalkyltrialkoxysilane. In one embodiment, an aliphatic silane chemical composition may be selected from the group consisting of 3-aminopropyl, N-(2-aminoethyl)-3-aminopropyl, vinyl, methyl, N-phenylaminopropyl, (N-phenylamino)methyl, N-(2-Vinylbenzylaminoethyl)-3-aminopropyl substituted alkoxy, acyloxy, ~~hylogen~~halogen, or amino silanes, hydrolysates thereof, or oligomers thereof. Aminoalkyltrialkoxysilanes, include, but are not limited to, 3-aminopropyltrimethoxy silane (sometimes referred to herein as "GAPS"), 3-aminopropyldimethoxy silane, 3-aminopropyltriethoxy silane, 3-aminopropyldiethoxy silane, N-(2-aminoethyl)-3-aminopropyltrimethoxysilane, N-(2-aminoethyl)-3-aminopropyldimethoxysilane, N-(2-aminoethyl)-3-aminopropyltriethoxysilane, N-(2-aminoethyl)-3-aminopropyldiethoxysilane, hydrolysates thereof, and oligomerized chemical composition thereof. In other embodiments, the aliphatic alkoxysilane chemical composition may not contain an amine moiety, such as an alkyltrialkoxysilane or alkylbialkoxysilane.

[00105] In the layered low-friction coating embodiment, after the glass body 102 is contacted with the coupling agent to form the coupling agent layer 180 and polyamic acid solution to ~~from~~form the polymer layer 170, the coated glass container 100 may be cured at high temperatures. The coated glass container 100 may be cured at 300°C for about 30 minutes or less, or may be cured at a temperature higher than 300°C, such as at least 320°C, 340°C, 360°C, 380°C, or 400°C for a shorter time. It is believed, without being bound by theory, that the curing step imidizes the polyamic acid in the polymer layer 170 by reaction of carboxylic acid moieties and amide moieties to create a polymer layer 170 comprising a polyimide. The curing may also promote bonds between the polyimide and the coupling agent. The coated glass container 100 is then cooled to room temperature.

[00106] Furthermore, without being bound by limitation, it is believed that the curing of the coupling agent, polymer chemical composition, or both, drives off volatile materials, such as water and other organic molecules. As such, these volatile materials that are liberated during curing are not present when the article, if used as a container, is thermally treated (such as for depyrogenation) or contacted by the material in which it is a package for, such as a pharmaceutical. It should be understood that the curing processes described herein are separate heating treatments than other heating treatments described herein, such as those heating treatments similar or identical to processes in the pharmaceutical packaging industry, such as depyrogenation or the heating treatments used to define thermal stability, as described herein.

[00107] The glass containers to which the low-friction coating 120 may be applied may be formed from a variety of different glass compositions. The specific composition of the glass article may be selected according to the specific application such that the glass has a desired set of physical properties.

[00108] The glass containers may be formed from a glass composition which has a coefficient of thermal expansion in the range from about $25x10^{-7}$/°C to $80x10^{-7}$/°C. For example, in some embodiments described herein, the glass body 102 is formed from alkali aluminosilicate glass compositions which are amenable to strengthening by ion exchange. Such compositions generally include a combination of SiO_2, Al_2O_3, at least one alkaline earth

glass containers 900 are conveyed to an oven 634 where they are heated from 150°C to approximately 350°C over a period of about 5 to 30 minutes. Upon removal of the glass containers from the oven, the polymer chemical composition coating is cured thereby producing a coated glass container with a low-friction coating.

[00134] After the low-friction coating has been applied to the glass container, the coated glass containers 100 are transferred to a packaging process in step 524 where the containers are filled and/or to an additional inspection station.

[00135] Various properties of the coated glass containers (i.e., coefficient of friction, horizontal compression strength, 4-point bend strength) may be measured when the coated glass containers are in an as-coated condition (i.e., following application of the coating without any additional treatments) or following one or more processing treatments, such as those similar or identical to treatments performed on a pharmaceutical filling line, including, without limitation, washing, lyophilization, depyrogenation, autoclaving, or the like.

[00136] Depyrogentation is a process wherein pyrogens are removed from a substance. Depyrogenation of glass articles, such as pharmaceutical packages, can be performed by a thermal treatment applied to a sample in which the sample is heated to an elevated temperature for a period of time. For example, depyrogenation may include heating a glass container to a temperature of between about 250°C and about 380°C for a time period from about 30 seconds to about 72 hours, including, without limitation, 20 minutes, 30 minutes 40 minutes, 1 hour, 2 hours, 4 hours, 8 hours, 12 hours, 24 hours, 48 hours, and 72 hours. Following the thermal treatment, the glass container is cooled to room temperature. One conventional depyrogenation condition commonly employed in the pharmaceutical industry is thermal treatment at a temperature of about 250°C for about 30 minutes. However, it is contemplated that the time of thermal treatment may be reduced if higher temperatures are utilized. The coated glass containers, as described herein, may be exposed to elevated temperatures for a period of time. The elevated temperatures and time periods of heating described herein may or may not be sufficient to depyrogenate a glass container. However, it should be understood that some of the temperatures and times of heating described herein are sufficient to dehydrogenate a coated glass container, such as the coated glass containers

procedure wherein a coated glass container 100 is placed in a glass sample chamber 402 of the apparatus 400 depicted in FIG. 10. A background sample of the empty sample chamber is collected prior to each sample run. The sample chamber is held under a constant 100 ml/min air purge as measured by rotometer 406 while the furnace 404 is heated to 350°C and held at that temperature for 1 hour to collect the chamber background sample. Thereafter, the coated glass container 100 is positioned in the sample chamber 402 and the sample chamber is held under a constant 100 ml/min air purge and heated to an elevated temperature and held at temperature for a period of time to collect a sample from a coated glass container 100. The glass sample chamber 402 is made of Pyrex, limiting the maximum temperature of the analysis to 600°C. A Carbotrap 300 adsorbent trap 408 is assembled on the exhaust port of the sample chamber to adsorb the resulting volatile species as they are released from the sample and are swept over the absorbent resin by the air purge gas 410 where the volatile species are adsorbed. The absorbent resin is then placed directly into a Gerstel Thermal Desorption unit coupled directly to a Hewlett Packard 5890 Series II gas chromatograph/Hewlett Packard 5989 MS engine. Outgassing species are thermally desorbed at 350°-C from the adsorbent resin and cryogenically focused at the head of a non-polar gas chromatographic column (DB-5MS). The temperature within the gas chromatograph is increased at a rate of 10°-C/min to a final temperature of 325°-C, so as to provide for the separation and purification of volatile and semi-volatile organic species. The mechanism of separation has been demonstrated to be based on the heats of vaporization of different organic species resulting in, essentially, a boiling point or distillation chromatogram. Following separation, purified species are analyzed by traditional electron impact ionization mass spectrometric protocols. By operating under standardized conditions, the resulting mass spectra may be compared with existing mass spectral libraries.

[00165] In some embodiments, the coated glass containers described herein exhibit an outgassing of less than or equal to about 54.6 ng/cm^2, less than or equal to about 27.3 ng/cm^2, or even less than or equal to about 5.5 ng/cm^2 during exposure to elevated temperature of about, 250°C, about 275°C, about 300°C, about 320°C, about 360°C, or even about 400°C for time periods of about 15 minutes, about 30 minutes, about 45 minutes, or about 1 hour. Furthermore, the coated glass containers may be thermally stable in a specified range of temperatures, meaning that the coated containers exhibit a certain outgassing, as described

passes through the low-friction coating twice, first when entering the container and then when exiting it. FIG. 11 graphically depicts the light transmittance data for coated and uncoated vials measured in the visible light spectrum from 400-700 nm. Line 440 shows an uncoated glass container and line 442 shows a coated glass container.

Example 19

[00204] Vials were coated with a 0.25% GAPS / 0.25% APhTMS coupling agent and 1.0% Novastrat® 800 polyimide and were tested for light transmission before and after depyrogenation at 320°C for 12 hours. An uncoated vial was also tested. Results are shown in FIG. 46.

Example 20

[00205] To improve polyimide coating uniformity, the Novastrat® 800 polyamic acid was converted into polyamic acid salt and dissolved in methanol, significantly faster evaporating solvent compard to dimethylacetamide, by adding 4 g of triethylamine to 1L of methanol and then adding Novastrat® 800 polyamic acid to form 0.1% solution.

[00206] Coating on 1B ion-exchanged vials formed from 1.0% GAPS/1.0% APhTMS in methanol/water mixture and 0.1% Novastrat® 800 polyamic acid salt in methanol. The coated vials were depyrogenated for 12h at 360°C and undepyrgenated and depyrogenated samples were scratched in vial-on-cial jig at 10, 20 and 30 N normal loads. No glass damage was observed at normal ~~formes~~forces of 10 N, 20 N and 30 N. FIG. 1 shows the coefficient of friction, applied force and frictive force for the samples after a heat treatment at 360°C for 12 hours. FIG. 42 graphically depicts the failure probability as a function of applied load in a horizontal compression test for the samples. Statistically the sample series at 10 N, 20N , and 30 N were indistinguishable from each other. The low load failure samples broke from ~~originesorigins~~ located away from the scratch.

[00207] Thickness of the coaing layers wes estimated using ellipsometry and scanning electron microscopy (SEM), shown in FIGS. 43-45, respectively. The samples for coating thickness measurements were produced using silicon wafer (ellipsometry) and glass slides

(SEM). The methods show thicknesses varying from 55 to 180 nm for silsesquioxane tie-layer and 35 nm for Novastrat® 800 poyamic acid salt.

Example 21

[00208] Plasma cleaned Si wafers pieces were dip coated using 0.5% GAPS, 0.5% APhTMS solution in 75/25 methanol/water vol/vol mixture. The coating was exposed to 120°C for 15 minutes. The coating thickness was determined using ellipsometry. Three samples were prepared, and had thicknesses of 92.1 nm, 151.7 nm, and 110.2 nm, respectively, with a standard deviation of 30.6 nm.

[00209] Glass slides were dip coated and examined with a scanning electron microscope. FIG. 43 shows an SEM image glass slide dipped in a coating solution of 1.0% GAPS, 1.0% APhTMS, and 0.3 NMP with an 8 mm/s pull out rate after a curing at 150°C for 15 minutes. The coating appears to be about 93 nm thick. FIG. 44 shows an SEM image glass slide dipped in a coating solution of 1.0% GAPS, 1.0% APhTMS, and 0.3% NMP with a 4 mm/s pull out rate after a curing at 150°C for 15 minutes. The coating appears to be about 55 nm thick. FIG. 45 shows an SEM image glass slide dipped in a coating solution of 0.5 Novastrat® 800 solution with a 2 mm/s pull up rate after a curing at 150°C for 15 min and heat treatment at 320°C for 30 minutes. The coating appears to be about 35 nm thick.

Comparative Example A

[00210] Glass vials formed from a Type 1B glass were coated with a diluted coating of Bayer Silicone aqueous emulsion of Baysilone M with a solids content of about 1-2%. The vials were treated at 150°C for 2 hours to drive away water from the surface leaving a polydimethylsiloxane coating on the exterior surface of the glass. The nominal thickness of the coating was about 200 nm. A first set of vials were maintained in untreated condition (i.e., the "as-coated vials"). A second set of vials were treated at 280°C for 30 minutes (i.e., the "treated vials"). Some of the vials from each set were first mechanically tested by applying a scratch with a linearly increasing load from 0-48N and a length of approximately 20 mm using a UMT-2 tribometer. The scratches were evaluated for coefficient of friction

composition and a second silane chemical composition; and a chemical composition formed from the oligomerization of at least the first silane chemical composition and the second silane chemical composition, wherein the first silane chemical composition and the second silane chemical composition are different chemical compositions.

[00242] A twenty-fifth aspect includes the coated glass article of twenty-fourth aspect, wherein the first silane chemical composition is an aromatic silane chemical composition.

[00243] A twenty-sixth aspect includes the coated glass article of the eighteenth aspect, wherein the first silane chemical composition is an aromatic silane chemical composition.

[00244] A twenty-seventh aspect includes the coated glass article of any of the second, sixth, or twenty-sixth aspects, wherein the first silane chemical composition comprises at least one amine moiety.

[00245] A twenty-eighth aspect includes the coated glass article of any of the second, sixth, or twenty-sixth aspects, wherein the first silane chemical composition is an aromatic alkoxysilane chemical composition, an aromatic acyloxysilane chemical composition, an aromatic halogen silane chemical composition, or an aromatic aminosilane chemical composition.

[00246] A twenty-ninth aspect includes the coated glass article of any of the second, sixth, or twenty-sixth aspects, wherein the first silane chemical composition is selected from the group consisting of aminophenyl, 3-(m-aminophenoxy) propyl, N-phenylaminopropyl, or (chloromethy) phenyl substituted alkoxy, acyloxy, ~~hylogen~~halogen, or amino silanes.

[00247] A thirtieth aspect includes the coated glass article of any of the second, sixth, or twenty-sixth aspects, wherein the first silane chemical composition is aminophenyltrimethoxy silane.

[00248] A thirty-first aspect includes the coated glass article of any of the second, sixth, or twenty-sixth aspects, wherein the coupling agent comprises at least one of: a mixture of the first silane chemical composition and the second silane chemical composition, wherein the second silane chemical composition is an aliphatic silane chemical composition; and a

chemical composition formed from the oligomerization of at least the first silane chemical composition and the second silane chemical composition.

[00249] A thirty-second aspect includes the coated glass article of the thirty-first aspect, wherein a molar ratio of the first silane chemical composition and the second silane chemical composition is from about 0.1:1 to about 10:1.

[00250] A thirty-third aspect includes the coated glass article of the thirty-first aspect, wherein the first silane chemical composition is an aromatic alkoxysilane chemical composition comprising at least one amine moiety and the second silane chemical composition is an aliphatic alkoxysilane chemical composition comprising at least one amine moiety.

[00251] A thirty-fourth aspect includes the coated glass article of the thirty-first aspect, wherein the first silane chemical composition is selected from the group consisting of aminophenyl, 3-(m-aminophenoxy) propyl, N-phenylaminopropyl, or (chloromethy) phenyl substituted alkoxy, acyloxy, ~~hylogen~~halogen, or amino silanes, hydrolysates thereof, or oligomers thereof, and the second silane chemical composition is selected from the group consisting of 3-aminopropyl, N-(2-aminoethyl)-3-aminopropyl, vinyl, methyl, N-phenylaminopropyl, (N-phenylamino)methyl, N-(2-Vinylbenzylaminoethyl)-3-aminopropyl substituted alkoxy, acyloxy, hylogen, or amino silanes, hydrolysates thereof, or oligomers thereof.

[00252] A thirty-fifth aspect includes the coated glass article of the thirty-first aspect, wherein the first silane chemical composition comprises at least one amine moiety and the second silane chemical composition comprises at least one amine moiety.

[00253] A thirty-sixth aspect includes the coated glass article of the thirty-first aspect, wherein the first silane chemical composition is aminophenyltrimethoxy silane and the second silane chemical composition is 3-aminopropyltrimethoxy silane.

[00254] A thirty-seventh aspect includes the coated glass article of the third or seventh aspects, wherein the oligomer is formed from at least aminophenyltrimethoxy silane.

[00255] A thirty-eighth aspect includes the coated glass article of the third or seventh aspects, wherein the oligomer is formed from at least aminophenyltrimethoxy silane and aminopropyltrimethoxy silane.

[00256] A thirty-ninth aspect includes the coated glass article of the third or seventh aspects, wherein the first diamine monomer chemical composition is ortho-Tolidine, the second diamine monomer chemical composition is 4,4'-methylene-bis(2-methylaniline), and the dianhydride monomer chemical composition is benzophenone-3,3',4,4'-tetracarboxylic dianhydride.

[00257] A fortieth aspect includes the coated glass article of any of the first, second, fourth, or fifth aspects, wherein the polymer chemical composition is a polyimide chemical composition.

[00258] A forty-first aspect includes the coated glass article of any of the first, second, fourth, or fifth aspects, wherein the polymer chemical composition is a polyimide chemical composition formed from the polymerization of: at least one monomer chemical composition comprising at least two amine moieties; and at least one monomer chemical composition comprising at least two anhydride moieties and having a benzophenone structure.

[00259] A forty-second aspect includes the coated glass article of the forty-~~fifth~~first aspect, wherein the monomer chemical composition comprising at least two anhydride moieties is benzophenone-3,3',4,4'-tetracarboxylic dianhydride.

[00260] A forty-third aspect includes the coated glass article of any of the first, second, fourth, or fifth aspects, wherein the polymer chemical composition is a polyimide chemical composition formed from the polymerization of at least: a first monomer chemical composition, the first monomer chemical composition comprising at least two amine moieties; a second monomer chemical composition, the second monomer chemical composition comprising at least two amine moieties; and a third monomer chemical composition, the third monomer chemical composition comprising at least two anhydride moieties; wherein the first monomer chemical composition is different than the second monomer chemical composition.

CLAIMS

1. A coated glass article comprising:

a glass body comprising a first surface; and

a low-friction coating positioned on at least a portion of the first surface of the glass body, the low-friction coating comprising a polymer chemical composition, wherein:

the coated glass article is thermally stable at a temperature of at least about 260°C for 30 minutes;

a light transmission through the coated glass article is greater than or equal to about 55% of a light transmission through an uncoated glass article for wavelengths from about 400 nm to about 700 nm; and

the low-friction coating has a mass loss of less than about 5% of its mass when heated from a temperature of 150°C to 350°C at a ramp rate of about 10°C/minute.

2. A coated glass article comprising:

a glass body comprising a first surface; and

a low-friction coating positioned on at least a portion of the first surface of the glass body, the low-friction coating comprising:

a polymer chemical composition; and

a coupling agent comprising at least one of:

a first silane chemical composition, a hydrolysate thereof, or an oligomer thereof, wherein the first silane chemical composition is an aromatic silane chemical composition; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and a second silane chemical composition, wherein:

the first silane chemical composition and the second silane chemical composition are different chemical compositions;

the coated glass article is thermally stable at a temperature of at least about 260°C for 30 minutes;

a light transmission through the coated glass article is greater than or equal to about 55% of a light transmission through an uncoated glass article for wavelengths from about 400 nm to about 700 nm; and

the low-friction coating has a mass loss of less than about 5% of its mass when heated from a temperature of 150°C to 350°C at a ramp rate of about 10°C/minute.

3. A coated glass article comprising:

a glass body comprising a first surface;

a low-friction coating positioned on at least a portion of the first surface of the glass body, the low-friction coating comprising:

a coupling agent comprising an oligomer of one or more silane chemical compositions, wherein the oligomer is a silsesquioxane chemical composition and at least one of the silane chemical compositions comprises at least one aromatic moiety and at least one amine moiety; and

a polyimide chemical composition formed from the polymerization of at least a first diamine monomer chemical composition, a second diamine monomer chemical composition, and a dianhydride monomer chemical composition, wherein the first diamine monomer chemical composition is different than the second diamine monomer chemical composition.

4. A coated glass article comprising:

a glass body comprising a first surface; and

a low-friction coating positioned on at least a portion of the first surface of the glass body, the low-friction coating comprising a polymer chemical composition, wherein:

the coated glass article is thermally stable at a temperature of at least about 300°C for 30 minutes; and

a light transmission through the coated glass article is greater than or equal to about 55% of a light transmission through an uncoated glass article for wavelengths from about 400 nm to about 700 nm.

5. A coated glass article comprising:

a glass body comprising a first surface and a second surface opposite the first surface, wherein the first surface is an exterior surface of a glass container; and

a low-friction coating bonded to at least a portion of the first surface of the glass body, the low-friction coating comprising a polymer chemical composition, wherein:

the coated glass article is thermally stable at a temperature of at least about 280°C for 30 minutes; and

a light transmission through the coated glass article is greater than or equal to about 55% of a light transmission through an uncoated glass article for wavelengths from about 400 nm to about 700 nm.

6. A coated glass article comprising:

a glass body comprising a first surface; and

a low-friction coating bonded to at least a portion of the first surface of the glass body, the low-friction coating comprising:

a coupling agent layer positioned on the first surface of the glass body, the coupling agent layer comprising a coupling agent, the coupling agent comprising at least one of:

a first silane chemical composition, a hydrolysate thereof, or an oligomer thereof, wherein the first silane chemical composition is an aromatic silane chemical composition; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and a second silane chemical composition,

a polymer layer positioned over the coupling agent layer, the polymer layer comprising a polyimide chemical composition; and

wherein:

the first silane chemical composition and the second silane chemical composition are different chemical compositions;

the coated glass article is thermally stable at a temperature of at least about 280°C for 30 minutes; and

a light transmission through the coated glass article is greater than or equal to about 55% of a light transmission through an uncoated glass article for wavelengths from about 400 nm to about 700 nm.

7. A coated glass article comprising:

a glass body comprising a first surface;

a low-friction coating bonded to at least a portion of the first surface of the glass body, the low-friction coating comprising:

a coupling agent layer comprising a coupling agent, the coupling agent comprising an oligomer of one or more silane chemical compositions, wherein the oligomer is a silsesquioxane chemical composition and at least one of the silane chemical compositions comprises at least one aromatic moiety and at least one amine moiety;

a polymer layer, the polymer layer comprising a polyimide chemical composition formed from the polymerization of at least a first diamine monomer chemical composition, a second diamine monomer chemical composition, and a dianhydride monomer chemical composition, wherein the first diamine monomer chemical composition is different than the second diamine monomer chemical composition; and

an interface layer comprising one or more chemical compositions of the polymer layer bound with one or more of the chemical compositions of the coupling agent layer.

8. The coated glass article of any of claims 1-4, 6 or 7, wherein:

the glass body is a glass container comprising a second surface opposite the first surface; and

the first surface is an exterior surface of the glass container.

9. The coated glass article of any of claims 1-7, wherein the coated glass article is a pharmaceutical package.

10. The coated glass article of claim 9, wherein the pharmaceutical package contains a pharmaceutical composition.

11. The coated glass article of any of claims 1-7, wherein the glass body comprises ion-exchanged glass.

12. The coated glass article of any of claims 1-5, wherein the low-friction coating comprises:

a coupling agent layer positioned on the first surface of the glass body, the coupling agent layer comprising the coupling agent; and

a polymer layer positioned over the coupling agent layer, the polymer layer comprising the polymer chemical composition.

13. The coated glass article of claims 6 or 12, wherein:

the low-friction coating further comprises an interface layer positioned between the coupling agent layer and the polymer layer; and

the interface layer comprises one or more chemical compositions of the polymer layer bound with one or more of the chemical compositions of the coupling agent layer.

14. The coated glass article of any of claims 1-7, wherein the coefficient of friction of the portion of the coated glass article with the low-friction coating is at least 20% less than a coefficient of friction of a surface of an uncoated glass article formed from a same glass composition.

15. The coated glass article of any of claims 1-7, wherein the portion of the coated glass article with the low-friction coating has a coefficient of friction of less than or equal to about 0.7 after exposure to autoclave conditions.

16. The coated glass article of any of claims 1-7, wherein the portion of the coated glass article with the low-friction coating has a coefficient of friction of less than or equal to about 0.7 after the coated glass article is submerged in a water bath at a temperature of about 70°C for 1 hour.

17. The coated glass article of any of claims 1-7, wherein the portion of the coated glass article with the low-friction coating has a coefficient of friction of less than or equal to about 0.7 after exposure to lyophilization conditions.

18. The coated glass article of any of claims 1, 4 or 5, wherein the low-friction coating further comprises a coupling agent.

19. The coated glass article of claim 18, wherein the coupling agent comprises at least one of:

a first silane chemical composition, a hydrolysate thereof, or an oligomer thereof; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and a second silane chemical composition, wherein the first silane chemical composition and the second silane chemical composition are different chemical compositions.

20. The coated glass article of claim 19, wherein the first silane chemical composition is an aromatic silane chemical composition.

21. The coated glass article of claim 18, wherein the coupling agent comprises a silsesquioxane chemical composition.

22. The coated glass article of claim 21, wherein the silsesquioxane chemical composition comprises an aromatic moiety.

23. The coated glass article of claim 22, wherein the silsesquioxane chemical composition further comprises an amine moiety.

24. The coated glass article of claim 18, wherein the coupling agent comprises at least one of:

a mixture of a first silane chemical composition and a second silane chemical composition; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and the second silane chemical composition, wherein the first silane chemical composition and the second silane chemical composition are different chemical compositions.

25. The coated glass article of claim 24, wherein the first silane chemical composition is an aromatic silane chemical composition.

26. The coated glass article of claim 18, wherein the first silane chemical composition is an aromatic silane chemical composition.

27. The coated glass article of any of claims 2, 6, or 26, wherein the first silane chemical composition comprises at least one amine moiety.

28. The coated glass article of any of claims 2, 6, or 26, wherein the first silane chemical composition is an aromatic alkoxysilane chemical composition, an aromatic acyloxysilane chemical composition, an aromatic halogen silane chemical composition, or an aromatic aminosilane chemical composition.

29. The coated glass article of any of claims 2, 6, or 26, wherein the first silane chemical composition is selected from the group consisting of aminophenyl, 3-(m-aminophenoxy) propyl, N-phenylaminopropyl, or (chloromethy) phenyl substituted alkoxy, acyloxy, hylogen, or amino silanes.

30. The coated glass article of any of claims 2, 6, or 26, wherein the first silane chemical composition is aminophenyltrimethoxy silane.

31. The coated glass article of any of claims 2, 6, or 26, wherein the coupling agent comprises at least one of:

a mixture of the first silane chemical composition and the second silane chemical composition, wherein the second silane chemical composition is an aliphatic silane chemical composition; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and the second silane chemical composition.

32. The coated glass article of claim 31, wherein a molar ratio of the first silane chemical composition and the second silane chemical composition is from about 0.1:1 to about 10:1.

33. The coated glass article of claim 31, wherein the first silane chemical composition is an aromatic alkoxysilane chemical composition comprising at least one amine moiety and the second silane chemical composition is an aliphatic alkoxysilane chemical composition comprising at least one amine moiety.

34. The coated glass article of claim 31, wherein the first silane chemical composition is selected from the group consisting of aminophenyl, 3-(m-aminophenoxy) propyl, N-phenylaminopropyl, or (chloromethyl) phenyl substituted alkoxy, acyloxy, hylogen, or amino silanes, hydrolysates thereof, or oligomers thereof, and the second silane chemical composition is selected from the group consisting of 3-aminopropyl, N-(2-aminoethyl)-3-aminopropyl, vinyl, methyl, N-phenylaminopropyl, (N-phenylamino)methyl, N-(2-Vinylbenzylaminoethyl)-3-aminopropyl substituted alkoxy, acyloxy, hylogen, or amino silanes, hydrolysates thereof, or oligomers thereof.

35. The coated glass article of claim 31, wherein the first silane chemical composition comprises at least one amine moiety and the second silane chemical composition comprises at least one amine moiety.

36. The coated glass article of claim 31, wherein the first silane chemical composition is aminophenyltrimethoxy silane and the second silane chemical composition is 3-aminopropyltrimethoxy silane.

37. The coated glass article any of claims 3 or 7, wherein the oligomer is formed from at least aminophenyltrimethoxy silane.

38. The coated glass article any of claims 3 or 7, wherein the oligomer is formed from at least aminophenyltrimethoxy silane and 3-aminopropyltrimethoxy silane.

39. The coated glass article any of claims 3 or 7, wherein the first diamine monomer chemical composition is ortho-Tolidine, the second diamine monomer chemical composition is 4,4'-methylene-bis(2-methylaniline), and the dianhydride monomer chemical composition is benzophenone-3,3',4,4'-tetracarboxylic dianhydride.

40. The coated glass article of any of claims 1, 2, 4, or 5, wherein the polymer chemical composition is a polyimide chemical composition.

41. The coated glass article of any of claims 1, 2, 4, or 5, wherein the polymer chemical composition is a polyimide chemical composition formed from the polymerization of:

at least one monomer chemical composition comprising at least two amine moieties; and

at least one monomer chemical composition comprising at least two anhydride moieties and having a benzophenone structure.

42. The coated glass article of claim 41, wherein the monomer chemical composition comprising at least two anhydride moieties is benzophenone-3,3',4,4'-tetracarboxylic dianhydride.

43. The coated glass article of any of claims 1, 2, 4, or 5, wherein the polymer chemical composition is a polyimide chemical composition formed from the polymerization of at least:

a first monomer chemical composition, the first monomer chemical composition comprising at least two amine moieties;

a second monomer chemical composition, the second monomer chemical composition comprising at least two amine moieties; and

a third monomer chemical composition, the third monomer chemical composition comprising at least two anhydride moieties;
wherein the first monomer chemical composition is different than the second monomer chemical composition.

44. The coated glass article of claim 43, wherein the third monomer chemical composition has a benzophenone structure.

45. The coated glass article of claim 44, wherein the third monomer composition is benzophenone-3,3',4,4'-tetracarboxylic dianhydride.

46. The coated glass article of claim 43, wherein the first monomer chemical composition comprises two aromatic ring moieties.

47. The coated glass article of claim 46, wherein the two aromatic ring moieties of the first monomer chemical composition are directly bonded to one another.

48. The coated glass article of claim 47, wherein the second monomer chemical composition comprises two aromatic ring moieties and the two aromatic ring moieties of the second monomer chemical composition are bonded with an alkyl moiety.

49. The coated glass article of claim 48, wherein a molar ratio of the first monomer chemical composition to the second monomer chemical composition is between about 0.01:0.49 to about 0.40:0.10.

50. The coated glass article of claim 46, wherein the two aromatic ring moieties of the first monomer chemical composition are bonded with an alkyl moiety.

51. The coated glass article of claim 46, wherein the first monomer chemical composition comprises a tolidine structure.

52. The coated glass article of claim 51, wherein the first monomer chemical composition is ortho-Tolidine.

53. The coated glass article of claim 51, wherein the first monomer chemical composition is 4,4'-methylene-bis(2-methylaniline).

54. The coated glass article of claim 51, wherein the first monomer chemical composition is ortho-Tolidine and the second monomer chemical composition is 4,4'-methylene-bis(2-methylaniline).

55. The coated glass article of claim 46, wherein the second monomer chemical composition comprises an aromatic ring moiety.

56. A coated glass article according to any of claims 5 or 6, wherein the low-friction coating has a mass loss of less than about 5% of its mass when heated from a temperature of 150°C to 350°C at a ramp rate of about 10°C/minute.

57. A low-friction coating for a substrate, the low-friction coating comprising:

a polyimide chemical composition; and

a coupling agent comprising at least one of:

a mixture of a first silane chemical composition, a hydrolysate thereof, or an oligomer thereof, and a second silane chemical composition, a hydrolysate thereof, or an oligomer thereof, wherein the first silane chemical composition is an aromatic silane chemical composition and the second silane chemical composition is an aliphatic silane chemical composition; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and the second silane chemical composition;

wherein:

the coated glass article is thermally stable at a temperature of at least about 260°C for 30 minutes;

a light transmission through the coating is greater than or equal to about 55%; and

the low-friction coating has a mass loss of less than about 5% of its mass when heated from a temperature of 150°C to 350°C at a ramp rate of about 10°C/minute.

58. The low-friction coating of claim 57, wherein the polyimide chemical composition is formed from the polymerization of:

at least one monomer chemical composition comprising at least two amine moieties; and

at least one monomer chemical composition comprising at least two anhydride moieties and having a benzophenone structure.

59. The low-friction coating of claim 57, wherein the polyimide chemical composition is formed from the polymerization of at least benzophenone-3,3',4,4'-tetracarboxylic dianhydride, ortho-Tolidine, and 4,4'-methylene-bis(2-methylaniline).

60. The low-friction coating of claim 57, wherein the first silane chemical composition comprises at least one amine moiety.

61. The low-friction coating of claim 57, wherein the first silane chemical composition is aminophenyltrimethoxy silane and the second silane chemical composition is 3-aminopropyltrimethoxy silane.

62. A coated glass article comprising:

a glass body comprising an exterior surface; and

a low-friction coating positioned on at least a portion of the exterior surface, the low-friction coating comprising a polymer chemical composition, wherein:

a coefficient of friction of an abraded area of the portion of the exterior surface with the low-friction coating is less than 0.7 after exposure to an elevated temperature of 280°C for 30 minutes and abrasion under a 30 N load and does not have observable damage; and

a retained strength of the coated glass article in horizontal compression does not decrease by more than about 20% after exposure to an elevated temperature of 280°C for 30 minutes and abrasion under a 30 N load.

CLAIMS

1. A coated glass article comprising:

a glass body comprising a first surface and a second surface opposite the first surface, wherein the first surface is an exterior surface of the glass article; and

a low-friction coating positioned on at least a portion of the first surface of the glass body, the low-friction coating comprising a polymer chemical composition, the low-friction coating having a thickness of less than or equal to about 1 micron and a coefficient of friction of less than or equal to 0.7 relative to a like coated glass article, wherein:

the coated glass article is thermally stable after depyrogenation at a temperature of at least about 280°C for 30 minutes in air;

a light transmission through the coated glass article is greater than or equal to about 55% of a light transmission through an uncoated glass article for wavelengths from about 400 nm to about 700 nm; and

the low-friction coating has a mass loss of less than about 5% of its mass when heated from a temperature of 150°C to 350°C at a ramp rate of about 10°C/minute.

2. The coated glass article of claim 1 wherein the low-friction coating further comprises a coupling agent positioned on the first surface of the glass body and the polymer chemical composition is positioned over the coupling agent.

3. The coated glass article of claim 2, wherein the coupling agent comprises at least one of:

a first silane chemical composition, a hydrolysate thereof, or an oligomer thereof; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and a second silane chemical composition, wherein the first silane chemical composition and the second silane chemical composition are different chemical compositions.

4. The coated glass article of claim 1, wherein the low-friction coating comprises:

a polyimide chemical composition; and

a coupling agent positioned between the polyimide chemical composition and the first surface of the glass body, the coupling agent comprising at least one of:

a mixture of a first silane chemical composition, a hydrolysate thereof, or an oligomer thereof, and a second silane chemical composition, a hydrolysate thereof, or an oligomer thereof, wherein the first silane chemical composition is an aromatic silane chemical composition and the second silane chemical composition is an aliphatic silane chemical composition; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and the second silane chemical composition.

5. A coated glass article comprising:

a glass body comprising a first surface; and

a low-friction coating positioned on at least a portion of the first surface of the glass body and having a coefficient of friction of less than or equal to 0.7 relative to a like coated glass article, the low-friction coating comprising:

a coupling agent layer positioned on the first surface of the glass body, the coupling agent layer comprising a coupling agent, the coupling agent comprising at least one of:

a first silane chemical composition, a hydrolysate thereof, or an oligomer thereof, wherein the first silane chemical composition is an aromatic silane chemical composition; and

a chemical composition formed from the oligomerization of at least the first silane chemical composition and a second silane chemical composition; and

a polymer layer positioned over the coupling agent layer, the polymer layer comprising a polyimide chemical composition, wherein:

the first silane chemical composition and the second silane chemical composition are different chemical compositions;

the coated glass article is thermally stable after depyrogenation at a temperature of at least about 280°C for 30 minutes in air; and

a light transmission through the coated glass article is greater than or equal to about 55% of a light transmission through an uncoated glass article for wavelengths from about 400 nm to about 700 nm.

6. The coated glass article of claim 3 or claim 5, wherein the first silane chemical composition is an aromatic alkoxysilane chemical composition comprising at least one amine moiety and the second silane chemical composition is an aliphatic alkoxysilane chemical composition comprising at least one amine moiety.

7. The coated glass article of claim 3 or claim 5, wherein the first silane chemical composition is aminophenyltrimethoxy silane and the second silane chemical composition is 3-aminopropyltrimethoxy silane.

8. The low-friction coating of claim 4 or claim 5, wherein the polyimide chemical composition is formed from the polymerization of:

at least one monomer chemical composition comprising at least two amine moieties; and

at least one monomer chemical composition comprising at least two anhydride moieties and having a benzophenone structure.

9. The low-friction coating of claim 4 or claim 5, wherein the polyimide chemical composition is formed from the polymerization of at least benzophenone-3,3',4,4'-tetracarboxylic dianhydride, ortho-Tolidine, and 4,4'-methylene-bis(2-methylaniline).

10. The coated glass article according to claim 5, wherein the low-friction coating has a mass loss of less than about 5% of its mass when heated from a temperature of 150°C to 350°C at a ramp rate of about 10°C/minute.