

Tertiary Azeotrope and Azeotrope-Like Compositions For Solvent and Cleaning Applications

TECHNICAL FIELD

[0001] This invention relates to tertiary azeotrope or azeotrope-like compositions comprising trans-dichloroethylene and two additional components. The compositions described herein may be useful, for example, in cleaning and defluxing fluid applications.

BACKGROUND

[0002] Chlorofluorocarbon (CFC) and hydrofluorocarbon (HFC) compounds have been used extensively in the area of semiconductor manufacture to clean surfaces such as magnetic disk media. However, chlorine-containing compounds such as CFC compounds are considered to be detrimental to the Earth's ozone layer. In addition, many of the hydrofluorocarbons used to replace CFC compounds have been found to contribute to global warming. Therefore, there is a need to identify new environmentally safe solvents for cleaning applications, such as removing residual flux, lubricant or oil contaminants, and particles. There is also a need for identification of new solvents for deposition of fluorolubricants.

SUMMARY

[0003] The present application provides, *inter alia*, a composition comprising:

- i) trans-1,2-dichloroethylene;
- ii) a second component which is a hydrofluoroether;
- iii) a third component selected from a compound selected from a hydrofluorocarbon and alkyl perfluoroalkene ether.

[0004] The present application further provides processes for removing at least a portion of residue from the surface of a substrate comprising contacting the substrate sufficient quantity of a composition described herein.

[0005] The present application further provides a processes for dissolving a solute, comprising contacting and mixing said solute with a sufficient quantity of a composition described herein.

[0006] The present application further provides a process removing at least a portion of water from the surface of a wetted substrate, comprising contacting the substrate with a composition described herein, and then removing the substrate from contact with the composition.

[0007] The present application further provides processes of depositing a fluorolubricant on a surface, comprising:

- a) combining a fluorolubricant and a solvent to form a lubricant-solvent combination, wherein the solvent comprises a composition provided herein;
 - b) contacting the lubricant-solvent combination with the surface;
- and
- c) evaporating the solvent from the surface to form a fluorolubricant coating on the surface.

[0008] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Methods and materials are described herein for use in the present invention; other, suitable methods and materials known in the art can also be used. The materials, methods, and examples are illustrative only and not intended to be limiting. All publications, patent applications, patents, sequences, database entries, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control.

DETAILED DESCRIPTION

[0009] Nonflammable fluorinated solvent based cleaning agents are useful in industrial vapor degreasing and flux removal applications. Hydrofluorocarbons (HFCs) and such blends have been successful in critical cleaning due to the combination of good safety and health attributes, zero ozone depletion, good solvency, and low viscosity properties. Recent environmental concerns and regulations have shifted from ozone depletion to global warming in view of global treaties (e.g., F-gas regulations in the European Union, SNAP rulings in the United States, and the like). Thus, there is a use for alternative cleaning agents, which are environmentally sustainable and exhibit low GWP. In addition, azeotrope and azeotrope-like compositions are desirable for critical cleaning applications, as such composition do not fractionate after distillation, condensation, and re-mixing. Azeotrope and azeotrope-like compositions therefore provide consistent cleaning performance, minimize solvent maintenance time, and improve production throughput. High solvency is also desirable for degreasing and removing flux residues from lead free and no clean solders on electronic components.

[0010] Accordingly, the present application provides new tertiary azeotropic and azeotrope-like compositions comprising mixtures of trans-dichloroethylene and two additional components. These compositions have utility in many of the applications formerly served by HFCs. The compositions of the present application possess some or all of the desired properties discussed above, little or no environmental impact, and the ability to dissolve oils, greases, and/or fluxes. Thus, the compositions provided herein may be useful as cleaning agents, defluxing agents, and/or degreasing agents.

Definitions and Abbreviations

[0011] As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having” or any other variation thereof, are intended to

cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, “or” refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0012] As used herein, the term “consisting essentially of” is used to define a composition, method that includes materials, steps, features, components, or elements, in addition to those literally disclosed provided that these additional included materials, steps, features, components, or elements do not materially affect the basic and novel characteristic(s) of the claimed invention, especially the mode of action to achieve the desired result of any of the processes of the present invention. The term “consists essentially of” or “consisting essentially of” occupies a middle ground between “comprising” and “consisting of”.

[0013] Also, use of “a” or “an” are employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

[0014] As used herein, the term “about” is meant to account for variations due to experimental error (e.g., plus or minus approximately 10% of the indicated value). All measurements reported herein are understood to be modified by the term “about”, whether or not the term is explicitly used, unless explicitly stated otherwise.

[0015] Throughout the definitions, the term “C_{n-m}” indicates a range, which includes the endpoints, wherein n and m are integers and indicate the number of carbons. Examples include C₁₋₆, C₅₋₈, and the like.

[0016] As used herein, the term “C_{n-m} alkyl”, refers to a saturated hydrocarbon group that may be straight-chain or branched, having n to m carbons. Exemplary alkyl moieties include, but are not limited to, methyl, ethyl, *n*-propyl, isopropyl, *n*-butyl, *tert*-butyl, isobutyl, *sec*-butyl, *n*-pentyl, 3-pentyl, *n*-hexyl, *n*-heptyl, *n*-octyl, and the like. In some embodiments, the alkyl group contains from 1 to 8 carbon atoms, from 5 to 8 carbon atoms, from 1 to 6 carbon atoms, from 1 to 3 carbon atoms, or from 1 to 2 carbon atoms.

[0017] As used herein, the term “C_{n-m} alcohol” refers to a group of formula (C_{n-m} alkyl)-OH, wherein the alkyl group has n to m carbon atoms. Exemplary alcohols include, but are not limited to methanol, ethanol, propanol, isopropanol, and butanol. In some embodiments, the alcohol is a C₁₋₆ alcohol.

[0018] As used herein, the term “C_{n-m} ketone” refers to a group of formula (C_{n-m} alkyl)C(O)(C_{n-m} alkyl), wherein each alkyl independently has n to m carbon atoms. Exemplary ketones include, but are not limited to dimethyl ketone (*i.e.*, acetone), ethyl methyl ketone, diethyl ketone, and the like. In some embodiments, the ketone is a C₃₋₆ ketone.

[0019] As used herein, the term “C_{n-m} alkane”, refers to a saturated hydrocarbon compound that may be straight-chain or branched, having n to m carbons. Exemplary alkanes include, but are not limited to methane, ethane, *n*-propane, isopropane, *n*-butane, *tert*-butane, isobutane, *sec*-butane, *n*-pentane, 3-pentane, *n*-hexane, *n*-heptane, *n*-octane, and the like. In some embodiments, the alkane is a C₅₋₈ alkane.

[0020] As used herein, the term “C_{n-m} cycloalkane” refers to non-aromatic cyclic hydrocarbon compound having n to m carbon atoms. Exemplary cycloalkanes include, but are not limited to cyclopropane, cyclobutane,

cyclopentane, cyclohexane, cycloheptane, cyclooctane, and the like. In some embodiments, the cycloalkane is a C₃₋₆ cycloalkane.

[0021] As used herein, the term “C_{n-m} alkyl acetate” refers to a compound of formula (C_{n-m} alkyl)OC(O)CH₃, wherein the alkyl has n to m carbon atoms. Exemplary alkyl acetates include, but are not limited to methyl acetate (*i.e.*, CH₃OC(O)CH₃), ethyl acetate (*i.e.*, CH₃CH₂OC(O)CH₃), propyl acetate (*i.e.*, CH₃CH₂CH₂OC(O)CH₃), isopropyl acetate (*i.e.*, (CH₃)₂CHOC(O)CH₃), and the like. In some embodiments, the alkyl acetate is a C₁₋₆ alkyl acetate. In some embodiments, the alkyl acetate is a C₁₋₃ alkyl acetate.

[0022] When an amount, concentration, or other value or parameter is given as either a range, preferred range or a list of upper preferable values and/or lower preferable values, this is to be understood as specifically disclosing all ranges formed from any pair of any upper range limit or preferred value and any lower range limit or preferred value, regardless of whether ranges are separately disclosed. Where a range of numerical values is recited herein, unless otherwise stated, the range is intended to include the endpoints thereof, and all integers and fractions within the range.

[0023] As recognized in the art, an azeotropic composition is an admixture of two or more different components which, when in liquid form and (1a) under a given constant pressure, will boil at a substantially constant temperature, which temperature may be higher or lower than the boiling temperatures of the individual components, or (1b) at a given constant temperature, will boil at a substantially constant pressure, which pressure may be higher or lower than the boiling pressure of the individual components, and (2) will boil at substantially constant composition, which phase compositions, while constant, are not necessarily equal (see, *e.g.*, M. F. Doherty and M.F. Malone, *Conceptual Design of Distillation Systems*, McGraw-Hill (New York), 2001, 185).

[0024] A homogeneous azeotrope, in which a single vapor phase is in equilibrium with a single liquid phase, has, in addition to properties (1a), (1b), and (2) above, the composition of each component is the same in each of the coexisting equilibrium phases. The general term “azeotrope” is a commonly used alternative name for a homogeneous azeotrope.

[0025] As used herein, an “azeotrope-like” composition refers to a composition that behaves like an azeotropic composition (*i.e.*, has constant boiling characteristics or a tendency not to fractionate upon boiling or evaporation). Hence, during boiling or evaporation, the vapor and liquid compositions, if they change at all, change only to a minimal or negligible extent. In contrast, the vapor and liquid compositions of non-azeotrope-like compositions change to a substantial degree during boiling or evaporation.

[0026] As used herein, the terms “azeotrope-like” or “azeotrope-like behavior” refer to compositions that exhibit dew point pressure and bubble point pressure with virtually no pressure differential. In some embodiments, the difference in the dew point pressure and bubble point pressure at a given temperature is 3% or less. In some embodiments, the difference in the bubble point and dew point pressures is 5% or less.

Chemical Abbreviations

[0027] The following abbreviations may be used throughout the present application.

CFC: chlorofluorocarbon

t-DCE: *trans*-1,2-dichloroethylene

HFC: hydrofluorocarbon

HFCP: 1,1,2,2,3,3,4-heptafluorocyclopentane

HFE: hydrofluoroether

HFE-7000: perfluoroisopropylmethyl ether

HFE-7100: mixture of 1-methoxyperfluorobutane and 1-methoxyperfluoroisobutane

HFE-7200: mixture of 1-ethoxyperfluorobutane and 1-ethoxyperfluoroisobutane

HFE-7300: 3-methoxyperfluoroisohexane

HFE-347pc-f: 1,1,2,2-tetrafluoroethyl-2,2,2-trifluoroethyl ether

MPHE: methyl perfluoroheptene ether

Novec™ 7300: 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-(trifluoromethyl)-pentane

Novec™ 7200: ethyl nonafluorobutyl ether

Azeotrope and Azeotrope-Like Compositions

[0028] The present application provides compositions, comprising:

- i) trans-1,2-dichloroethylene;
- ii) a second component which is a hydrofluoroether;
- iii) a third component selected from a compound selected from a hydrofluorocarbon and alkyl perfluoroalkene ether.

[0029] In some embodiments, the composition does not further comprise a compound selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate.

[0030] In some embodiments, the composition does not further comprise a compound selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate.

[0031] In some embodiments, the composition does not further comprise two or more compounds selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate. In some embodiments, the composition does not further comprise three or more compounds selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate. In some embodiments, the composition does not further comprise four or more compounds selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate. In some embodiments, the composition does not further comprise five or more

compounds selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate. In some embodiments, the composition does not further comprise six or more compounds selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate. In some embodiments, the composition does not further comprise six or more compounds selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate. In some embodiments, the composition does not further comprise a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate.

[0032] In some embodiments, the composition does not further comprise a C₁₋₆ alcohol. In some embodiments, the composition does not further comprise a C₃₋₆ ketone. In some embodiments, the composition does not further comprise a C₅₋₈ alkane. In some embodiments, the composition does not further comprise a C₃₋₆ cycloalkane. In some embodiments, the composition does not further comprise a C₁₋₆ alkyl acetate.

[0033] In some embodiments, the composition does not further comprise a compound selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate. In some embodiments, the composition does not further comprise a compound selected from methanol, ethanol, and isopropanol. In some embodiments, the composition does not further comprise acetone. In some embodiments, the composition does not further comprise n-hexane. In some embodiments, the composition does not further comprise cyclopentane. In some embodiments, the composition does not further comprise ethyl acetate.

[0034] In some embodiments, the composition does not further comprise one or more compounds selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate. In some embodiments, the composition does not further comprise two or more compounds selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and

ethyl acetate. In some embodiments, the composition does not further comprise three or more compounds selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate. In some embodiments, the composition does not further comprise four or more compounds selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate. In some embodiments, the composition does not further comprise five or more compounds selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate. In some embodiments, the composition does not further comprise six compounds or more selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate. In some embodiments, the composition does not further comprise methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate.

[0035] In some embodiments, the composition is an azeotrope (*i.e.*, azeotropic) composition. In some embodiments, the second and third components are present in the composition in amounts effective to form an azeotrope composition with trans-1,2-dichloroethylene. In some embodiments, the composition is an azeotrope-like composition. In some embodiments, the second and third components are present in the composition in amounts effective to form an azeotrope-like composition with trans-1,2-dichloroethylene.

[0036] In some embodiments, the hydrofluoroether is selected from HFE-7000, HFE-7100, HFE-7200, HFE-7300, and HFE-347pc-f. In some embodiments, the hydrofluoroether is selected from HFE-7200 and HFE-7300. In some embodiments, the hydrofluoroether is HFE-720. In some embodiments, the hydrofluoroether is HFE-7300.

[0037] In some embodiments, the composition comprises about 5 weight percent to about 45 weight percent HFE-7200. In some embodiments, the composition comprises about 5 to about 40, about 5 to about 38, about 7 to

about 35, about 10 to about 30, about 12 to about 28, about 15 to about 25, or about 15 to about 23 weight percent HFE-7200. In some embodiments, the composition comprises about 10 to about 30 weight percent HFE-7200. In some embodiments, the composition comprise about 33, about 25, about 15, or about 10 weight percent HFE-7200. In some embodiments, the composition comprises about 23 weight percent HFE-7200. In some embodiments, the composition comprises about 15 weight percent HFE-7200.

[0038] In some embodiments, the composition comprises about 1 weight percent to about 30 weight percent HFE-7300. In some embodiments, the composition comprises about 1 to about 28, about 1 to about 25, about 3 to about 25, about 5 to about 25, about 5 to about 22, or about 5 to about 20, about 7 to about 18, about 10 to about 15, or about 11 to about 13 weight percent HFE-7300. In some embodiments, the composition comprises about 1 to about 20 weight percent HFE-7300. In some embodiments, the composition comprises about 5 to about 20 weight percent HFE-7300. In some embodiments, the composition comprises about 3, about 4, about 6, about 10, about 12, about 14, about 15, about 17, about 18, or about 19 weight percent HFE-7300. In some embodiments, the composition comprises about 12 weight percent HFE-7300.

[0039] In some embodiments, the third component is a hydrofluorocarbon. In some embodiments, the hydrofluorocarbon is selected from heptafluorocyclopentane, pentafluorobutane, and pentafluoropropane. In some embodiments, the hydrofluorocarbon is heptafluorocyclopentane. In some embodiments, the hydrofluorocarbon is pentafluorobutane. In some embodiments, the hydrofluorocarbon is pentafluoropropane. In some embodiments, the hydrofluorocarbon is selected from 1,1,2,2,3,3,4-heptafluorocyclopentane, 1,1,1,3,3-pentafluorobutane, and 1,1,1,3,3-pentafluoropropane. In some embodiments, the hydrofluorocarbon is 1,1,2,2,3,3,4-heptafluorocyclopentane. In some embodiments, the

hydrofluorocarbon is 1,1,1,3,3-pentafluorobutane. In some embodiments, the hydrofluorocarbon is 1,1,1,3,3-pentafluoropropane.

[0040] In some embodiments, the composition comprises about 1 weight percent to about 30 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane. In some embodiments, the composition comprises about 1 to about 28, about 1 to about 25, about 1 to about 22, about 1 to about 20, about 1 to about 18, about 1 to about 15, about 3 to about 15, or about 4 to about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane. In some embodiments, the composition comprises about 1 to about 20 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane. In some embodiments, the composition comprises about 1 to about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane. In some embodiments, the composition comprises about 2, about 4, about 5, about 9, about 10, about 11, about 15, about 17, or about 22 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane. In some embodiments, the composition comprises about 4 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane. In some embodiments, the composition comprises about 9 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane. In some embodiments, the composition comprises about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0041] In some embodiments, the third component is an alkyl perfluoroalkene ether. In some embodiments, the alkyl perfluoroalkene ether is methyl perfluoroheptene ether. In some embodiments, the methyl perfluoroheptene ether comprises a mixture of about 50 weight percent 5-methoxy perfluoro-3-heptene, about 20 weight percent 3-methoxy perfluoro-3-heptene, about 20 weight percent 4-methoxy perfluoro-2-heptene, and about 8 weight percent 4-methoxy perfluoro-3-heptene.

[0042] In some embodiments, the composition comprises about 1 weight percent to about 5 weight percent methyl perfluoroheptene ether. In some embodiments, the composition comprises about 1 to about 4, about 2 to

about 4, or about 3 to about 4 weight percent methyl perfluoroheptene ether. In some embodiments, the composition comprises about 3, about 4, or about 5 weight percent methyl perfluoroheptene ether.

[0043] In some embodiments, the composition comprises about 65 weight percent to about 98 weight percent trans-1,2-dichloroethylene. In some embodiments, the composition comprises about 65 to about 95, about 65 to about 93, about 65 to about 92, or about 75 to about 80 weight percent trans-1,2-dichloroethylene. In some embodiments, the composition comprises about 65 to about 85, about 68 to about 82, about 70 to about 80, about 72 to about 80, about 75 to about 80 weight percent trans-1,2-dichloroethylene. In some embodiments, the composition comprises about 75 to about 90 or about 65 to about 85 weight percent trans-1,2-dichloroethylene. In some embodiments, the composition comprises about 79, about 73, or about 70 weight percent trans-1,2-dichloroethylene.

[0044] In some embodiments, the composition comprises trans-1,2-dichloroethylene, HFE-7300, and heptafluorocyclopentane. In some embodiments, the composition comprises trans-1,2-dichloroethylene, HFE-7300, and 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0045] In some embodiments, the composition comprises:

- i) about 75 weight percent to about 90 weight percent trans-1,2-dichloroethylene;
 - ii) about 1 weight percent to about 20 weight percent HFE-7300;
- and
- iii) about 1 weight percent to about 20 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

In some embodiments, the composition comprises:

- i) about 75 weight percent to about 85 weight percent trans-1,2-dichloroethylene;

- ii) about 5 weight percent to about 15 weight percent HFE-7300;
- and
- iii) about 1 weight percent to about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0046] In some embodiments, the composition comprises:

- i) about 79 weight percent trans-1,2-dichloroethylene;
- ii) about 12 weight percent HFE-7300; and
- iii) about 9 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0047] In some embodiments, the composition comprises trans-1,2-dichloroethylene, HFE-7200, and heptafluorocyclopentane. In some embodiments, the composition comprises trans-1,2-dichloroethylene, HFE-7200, and 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0048] In some embodiments, the composition comprises:

- i) about 65 weight percent to about 85 weight percent trans-1,2-dichloroethylene;
 - ii) about 10 weight percent to about 30 weight percent HFE-7200;
- and
- iii) about 1 weight percent to about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

In some embodiments, the composition comprises:

- i) about 68 weight percent to about 78 weight percent trans-1,2-dichloroethylene;
 - ii) about 18 weight percent to about 28 weight percent HFE-7200;
- and
- iii) about 1 weight percent to about 8 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0049] In some embodiments, the composition comprises:

- i) about 73 weight percent trans-1,2-dichloroethylene;

- ii) about 23 weight percent HFE-7200; and
- iii) about 4 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

In some embodiments, the composition comprises:

- i) about 65 weight percent to about 75 weight percent trans-1,2-dichloroethylene;
 - ii) about 10 weight percent to about 20 weight percent HFE-7200;
- and
- iii) about 10 weight percent to about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0050] In some embodiments, the composition comprises:

- i) about 70 weight percent trans-1,2-dichloroethylene;
- ii) about 15 weight percent HFE-7200; and
- iii) about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0051] In some embodiments, the composition comprises trans-1,2-dichloroethylene, HFE-7300, and methyl perfluoroheptene ether.

[0052] In some embodiments, the composition comprises:

- i) about 75 weight percent to about 90 weight percent trans-1,2-dichloroethylene;
 - ii) about 5 weight percent to about 20 weight percent HFE-7300;
- and
- iii) about 1 weight percent to about 5 weight percent methyl perfluoroheptene ether.

In some embodiments, the composition comprises:

- i) about 80 weight percent to about 85 weight percent trans-1,2-dichloroethylene;
 - ii) about 10 weight percent to about 15 weight percent HFE-7300;
- and
- iii) about 1 weight percent to about 5 weight percent methyl perfluoroheptene ether.

Methods of Use

[0053] In some embodiments, the compositions described herein may be useful as cleaning agents, defluxing agents, and/or degreasing agents. Accordingly, the present application provides a process of cleaning a surface, comprising contacting a composition provided herein with said surface. In some embodiments, the process comprises removing a residue from a surface or substrate, comprising contacting the surface or substrate with a composition provided herein and recovering the surface or substrate from the composition. In some embodiments, the present application further provides a process for removing at least a portion of residue from the surface of a substrate comprising contacting the substrate with a composition provided herein. In some embodiments, the present application further provides a process for dissolving a solute, comprising contacting and mixing said solute with a sufficient quantity of the composition disclosed herein. In some embodiments, the present application further provides a process of cleaning a surface, comprising contacting the composition disclosed herein with said surface.

[0054] In some embodiments, the surface or substrate may be an integrated circuit device, in which case, the residue comprises rosin flux or oil. The integrated circuit device may be a circuit board with various types of components, such as Flip chips, μ BGAs, or Chip scale packaging components. The surface or substrate may additionally be a metal surface such as stainless steel. The rosin flux may be any type commonly used in the soldering of integrated circuit devices, including but not limited to RMA (rosin mildly activated), RA (rosin activated), WS (water soluble), and OA (organic acid). Oil residues include but are not limited to mineral oils, motor oils, and silicone oils. In some embodiments, the surface or substrate is magnetic disk media. In some embodiments, the residue is flux, lubricant, grease, oil, wax, or combination thereof.

[0055] In some embodiments, the present application provides a process for removing at least a portion of water from the surface of a wetted substrate, or surface, or device, comprising contacting the substrate, surface, or device with a composition provided herein, and then removing the substrate, surface, or device from contact with the composition.

[0056] In some embodiments, the compositions provided herein further comprises one or more additive components (*i.e.*, the compositions comprise *trans*-1,2-dichloroethylene, a second component as described herein, a third component as described herein, and one or more additive components as described herein). Exemplary additives include, but are not limited to, propellants, surfactants, and fluorolubricants.

[0057] In some embodiments, the composition described herein further comprises a propellant. In some embodiments, the propellant is air, nitrogen, carbon dioxide, 2,3,3,3-tetrafluoropropene, *trans*-1,3,3,3-tetrafluoropropene, 1,2,3,3,3-pentafluoropropene, difluoromethane, trifluoromethane, difluoroethane, trifluoroethane, tetrafluoroethane, pentafluoroethane, hydrocarbons, dimethyl ether, or any mixture thereof.

[0058] In some embodiments, the compositions provided herein further comprises at least one surfactant suitable for dewatering or drying the substrate. Exemplary surfactants include, but are not limited to, alkyl dimethyl ammonium isooctyl phosphates, *tert*-alkyl amines (*e.g.*, *tert*-butyl amine), perfluoro alkyl phosphates, dimethyl decenamide, fluorinated alkyl polyether, quaternary amines (*e.g.*, ammonium salts), and glycerol monostearate.

[0059] The means for contacting a device, surface, or substrate is not critical and may be accomplished, for example, by immersion of the device, surface, or substrate, in a bath containing the composition provided herein, spraying the device, surface, or substrate with the composition provided herein, or wiping the device, surface, or substrate with a material (*e.g.*, a cloth) that has been wet with the composition. In some embodiments, the

contacting is accomplished by immersing the substrate in the composition. In some embodiments, the composition is at a temperature greater than ambient temperature or room temperature. In some embodiments, the composition is at a temperature of about the boiling point of the composition. In some embodiments, the composition further comprises a second immersion of the substrate in the composition, wherein said composition is at a temperature lower than the temperature of the first immersing step. In some embodiments, the composition in the second immersing step is at ambient temperature or room temperature.

[0060] Alternatively, a composition provided herein may also be used in a vapor degreasing or defluxing apparatus designed for such residue removal. Such vapor degreasing or defluxing equipment is available from various suppliers such as Forward Technology (a subsidiary of the Crest Group, Trenton, NJ), Trek Industries (Azusa, CA), and Ultronix, Inc. (Hatfield, PA) among others. In some embodiments, the vapor degreasing is performed by boiling the composition to form vapors of said composition and exposing at least a portion of residue from the surface of a substrate to said vapors.

[0061] The most advanced, highest recording densities and lowest cost method of storing digital information involves writing and reading magnetic flux patterns from rotating disks coated with magnetic materials. A magnetic layer, where information is stored in the form of bits, is sputtered onto a metallic support structure. Next an overcoat, usually a carbon-based material, is placed on top of the magnetic layer for protection and finally a lubricant is applied to the overcoat. A read-write head flies above the lubricant and the information is exchanged between the head and the magnetic layer. In a relentless attempt to increase the efficiency of information transfer, hard drive manufacturers have reduced the distance between the head and the magnetic layer, or fly-height, to less than 100 Angstroms.

[0062] Invariably, during normal disk drive application, the head and the disk surface will make contact. To reduce wear on the disk, from both sliding and flying contacts, it must be lubricated.

[0063] Fluorolubricants are widely used as lubricants in the magnetic disk drive industry to decrease the friction between the head and disk, that is, reduce the wear and therefore minimize the possibility of disk failure.

[0064] There is a need in the industry for improved methods for deposition of fluorolubricants. The use of certain solvents, such as CFC-113 and PFC-5060, has been regulated due to their impact on the environment. Therefore, solvents that will be used in this application should consider environmental impact. Also, such solvent must dissolve the fluorolubricant and form a substantially uniform or uniform coating of fluorolubricant. Additionally, existing solvents have been found to require higher fluorolubricant concentrations to produce a given thickness coating and produce irregularities in uniformity of the fluorolubricant coating.

[0065] In some embodiments, the present application provides a process of depositing a fluorolubricant on a surface, comprising combining a fluorolubricant and a solvent to form a lubricant-solvent combination, wherein the solvent comprises a composition provided herein, contacting the lubricant-solvent combination with the surface, and evaporating the solvent from the surface to form a fluorolubricant coating on the surface.

[0066] In some embodiments, the fluorolubricants of the present disclosure comprise perfluoropolyether (PFPE) compounds, or lubricant comprising X-1P®, which is a phosphazene-containing disk lubricant. These perfluoropolyether compounds are sometimes referred to as perfluoroalkylethers (PFAE) or perfluoropolyalkylethers (PFPAE). These PFPE compounds range from simple perfluorinated ether polymers to functionalized perfluorinated ether polymers. PFPE compounds of different varieties that may be useful as fluorolubricant in the present invention are

available from several sources. In some embodiments, fluorolubricants useful in the processes provided herein include, but are not limited to, Krytox[®] GLP 100, GLP 105 or GLP 160 (The Chemours Co., LLC, Fluoroproducts, Wilmington, DE, 19898, USA); Fomblin[®] Z-Dol 2000, 2500 or 4000, Z-Tetraol, or Fomblin[®] AM 2001 or AM 3001 (sold by Solvay Solexis S.p.A., Milan, Italy); Demnum[™] LR-200 or S-65 (offered by Daikin America, Inc., Osaka, Japan); X-1P[®] (a partially fluorinated hyxaphenoxy cyclotriphosphazene disk lubricant available from Quixtor Technologies Corporation, a subsidiary of Dow Chemical Co, Midland, MI); and mixtures thereof. The Krytox[®] lubricants are perfluoroalkylpolyethers having the general structure $F(CF(CF_3)CF_2O)_n-CF_2CF_3$, wherein n ranges from 10 to 60. The Fomblin[®] lubricants are functionalized perfluoropolyethers that range in molecular weight from 500 to 4000 atomic mass units and have general formula $X-CF_2-O(CF_2-CF_2-O)_p-(CF_2O)_q-CF_2-X$, wherein X may be $-CH_2OH$, $p+q$ is 40 to 180, and p/q is 0.5 to 2; $CH_2(O-CH_2-CH_2)_nOH$, wherein n is 10 to 60, $CH_2OCH_2CH(OH)CH_2OH$, or $-CH_2O-CH_2$ -piperonyl. The Demnum[™] oils are perfluoropolyether-based oils ranging in molecular weight from 2700 to 8400 atomic mass units. Additionally, new lubricants are being developed such as those from Moresco (Thailand) Co., Ltd, which may be useful in processes provided herein.

[0067] The fluorolubricants described herein may additionally comprise additives to improve the properties of the fluorolubricant. X-1P[®], which may serve as the lubricant itself, is often added to other lower cost fluorolubricants in order to increase the durability of disk drives by passivating Lewis acid sites on the disk surface responsible for PFPE degradation. Other common lubricant additives may be used in the fluorolubricants useful in the processes provided herein.

[0068] The fluorolubricants described herein may further comprise Z-DPA (Hitachi Global Storage Technologies, San Jose, CA), a PFPE terminated

with dialkylamine end-groups. The nucleophilic end-groups serve the same purpose as X1P®, thus providing the same stability without any additive.

[0069] The surface on which the fluorolubricant may be deposited is any solid surface that may benefit from lubrication. Semiconductor materials such as silica disks, metal or metal oxide surfaces, vapor deposited carbon surfaces or glass surfaces are representative of the types of surfaces that may be used in the processes described herein. In some embodiments, the processes provided herein are particularly useful in coating magnetic media such as computer drive hard disks. In the manufacture of computer disks, the surface may be a glass, or aluminum substrate with layers of magnetic media that is also coated by vapor deposition with a thin (10-50 Angstrom) layer of amorphous hydrogenated or nitrogenated carbon. The fluorolubricant may be deposited on the surface disk indirectly by applying the fluorolubricant to the carbon layer of the disk.

[0070] The first step of combining the fluorolubricant and composition provided herein (*i.e.*, as a solvent) may be accomplished in any suitable manner such as mixing in a suitable container such as a beaker or other container that may be used as a bath for the deposition process. The fluorolubricant concentration in the composition provided herein may be from about 0.010 percent (wt/wt) to about 0.50 percent (wt/wt).

[0071] The step of contacting said combination of fluorolubricant and composition provided herein with the surface may be accomplished in any manner appropriate for said surface (considering the size and shape of the surface). A hard drive disk must be supported in some manner such as with a mandrel or some other support that may fit through the hole in the center of the disk. The disk will thus be held vertically such that the plane of the disk is perpendicular to the solvent bath. The mandrel may have different shapes including but not limited to, a cylindrical bar, or a V-shaped bar. The mandrel shape will determine the area of contact with the disk. The mandrel may be

constructed of any material strong enough to hold the disk, including but not limited to metal, metal alloy, plastic, or glass. Additionally, a disk may be supported vertically upright in a woven basket or be clamped into a vertical position with one or more clamps on the outer edge. The support may be constructed of any material with the strength to hold the disk, such as metal, metal alloy, plastic or glass. However the disk is supported, the disk will be lowered into a container holding a bath of the fluorolubricant/solvent (*i.e.*, the composition provided herein) combination. The bath may be held at room temperature or be heated or cooled to temperatures ranging from about 0 °C to about 50 °C.

[0072] Alternatively, the disk may be supported as described above and the bath may be raised to immerse the disk. In either case, the disk may then be removed from the bath (either by lowering the bath or by raising the disk). Excess fluorolubricant/solvent combination can be drained into the bath.

[0073] Either of the processes for contacting the fluorolubricant/solvent combination with the disk surface of either lowering the disk into a bath or raising a bath to immerse the disk are commonly referred to as dip coating. Other processes for contacting the disk with the fluorolubricant/solvent combination may be used in processes described hererin, including, but not limited to, spraying or spin coating.

[0074] When the disk is removed from the bath, the disk will have a coating of fluorolubricant and some residual solvent (*i.e.*, the composition provided herein) on its surface. The residual solvent may be evaporated. Evaporation is usually performed at room temperature. However, other temperatures both above and below room temperature may be used as well for the evaporation step. Temperatures ranging from about 0 °C to about 100 °C may be used for evaporation.

[0075] The surface, or the disk if the surface is a disk, after completion of the coating process, will be left with a substantially uniform or uniform coating

of fluorolubricant that is substantially free of solvent. The fluorolubricant may be applied to a thickness of less than about 300 nm, and alternately to a thickness of about 100 to about 300 nm.

[0076] A uniform fluorolubricant coating is desired for proper functioning of a disk and so areas of varying fluorolubricant thickness are undesirable on the surface of the disk. As more and more information is being stored on the same size disk, the read/write head must get closer and closer to the disk in order to function properly. If irregularities due to variation in coating thickness are present on the surface of the disk, the probability of contact of the head with these areas on the disk is much greater. While there is a desire to have enough fluorolubricant on the disk to flow into areas where it may be removed by head contact or other means, coating that is too thick may cause “smear,” a problem associated with the read/write head picking up excess fluorolubricant.

[0077] One specific coating thickness irregularity observed in the industry is that known as the “rabbit ears” effect. These irregularities are visually detected on the surface of the disk after deposition of the fluorolubricant using the existing solvent systems. When the disk is contacted with the solution of fluorolubricant in solvent and then removed from the solution, any points where the solution may accumulate and not drain readily develop drops of solution that do not readily drain off. One such point of drop formation is the contact point (or points) with the mandrel or other support device with the disk. When a V-shaped mandrel is used, there are two contact points at which the mandrel contacts the inside edge of the disk. When solution of fluorolubricant forms drops in these locations that do not drain off when removed from the bath, an area of greater thickness of fluorolubricant is created when the solvent evaporates. The two points of contact with the disk produces what is known as a “rabbit ears” effect, because the areas of greater fluorolubricant thickness produce a pattern resembling rabbit ears visually detectable on the disk surface.

[0078] When dip coating is used for depositing fluorolubricant on the surface, the pulling-up speed (speed at which the disk is removed from the bath), and the density of the fluorolubricant and the surface tension are relevant for determining the resulting film thickness of the fluorolubricant. Awareness of these parameters for obtaining the desired film thickness is required. Details on how these parameters effect coatings are given in, "Dip-Coating of Ultra-Thin Liquid Lubricant and its Control for Thin-Film Magnetic Hard Disks" in IEEE Transactions on Magnetism, vol. 31, no. 6, November 1995, the disclosure of which is incorporated herein by reference in its entirety.

EXAMPLES

[0079] The invention will be described in greater detail by way of specific examples. The following examples are offered for illustrative purposes, and are not intended to limit the invention in any manner. Those of skill in the art will readily recognize a variety of non-critical parameters which can be changed or modified to yield essentially the same results.

Example 1. Distillation Analysis of Composition 1

[0080] A mixture of 79.85% trans-1,2-dichloroethylene (t-DCE), 10.19% 1,1,2,2,3,3,4-heptafluorocyclopentane (HFCP), and 9.95% 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-(trifluoromethyl)-pentane (Novec™ 7300) (Composition 1) was prepared gravimetrically and distilled at atmospheric pressure using a 25 plate Oldershaw distillation column. The distillation was refluxed for one hour, and then a ten percent distillate fraction was secured and analyzed via GC/FID. As shown in Table 1, after distillation with a 25-plate column, the composition did not significantly change and the distillate indicates a more preferred azeotropic composition of about 9% HFCP, 12% HFCP, and 79% t-DCE. The boiling point was also recorded, which was lower than the boiling point of neat t-DCE (48.4 °C) confirming the azeotropic behavior.

Table 1.

Component	Initial Composition (wt %)	Distillate Composition (wt %)
HFCP	10.19	8.93
Novec™ 7300	9.95	12.03
t-DCE	79.85	79.04
Boiling point (°C)	47.6	

Example 2. Distillation Analysis of Composition 2

[0081] A mixture of 64.59% trans-1,2-dichloroethylene, 10.59% 1,1,2,2,3,3,4-heptafluorocyclopentane (HFCP), and 24.81% ethyl nonafluorobutyl ether (Novec™ 7200) (Composition 2) was prepared gravimetrically and distilled at atmospheric pressure using the 25 plate Oldershaw distillation column. The distillation was refluxed for one hour, and then a ten percent distillate fraction was secured and analyzed via GC/FID. As shown in Table 2, the distillate composition data comprising all three initial components demonstrated the presence of a ternary azeotrope, preferably containing about 4.4% HFCP, 23.1% Novec 7200, and about 73.5% t-DCE. Additionally, the depressed boiling point of 45.5°C confirmed the azeotropic behavior.

Table 2.

Component	Initial Composition (wt %)	Distillate Composition (wt %)
HFCP	10.59	4.4
Novec™ 7200	24.81	23.11
t-DCE	64.59	72.49
Boiling point (°C)	45.5	

Example 3. Distillation Analysis of Composition 3

[0082] A mixture of 76.8% trans-1,2-dichloroethylene (t-DCE), 18.3% 3-methoxy-4-trifluoromethyldecafluoropentane (HFE-7300), and 4.9% heptafluorocyclopentane (HFCP) were prepared (Composition 3) and distilled

at atmospheric pressure using a single-plate distillation apparatus. The mixture was distilled until 50% by weight of the composition was distilled. The following distillation cuts and heel were collected and analyzed via GC/FID, and the temperature of the boiling flask and vapor dew points were recorded throughout the distillation. The results of the fractional distillation of the ternary azeotrope-like Composition 3 are listed in Table 3 below.

Table 3.

Component	Initial	10%	20%	30%	40%	50%	50% Heel
t-DCE	76.8%	78.1%	78.1%	78.1%	78.0%	78.1%	75.1%
HFE-7300	18.3%	17.0%	17.0%	17.0%	17.1%	17.0%	19.9%
HFCP	4.9%	4.9%	4.9%	4.9%	4.9%	4.9%	5.0%

[0083] Table 4 shows the boiling point (BP) and dew point (DP) through distillation of Composition 3.

Table 4.

	Initial	10%	20%	30%	40%	50%
BP (°C)	46.2	46.4	46.5	46.5	46.5	46.5
DP (°C)	46	46	46	46	46	46

[0084] Throughout the distillation of Composition 3, the boiling temperatures and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7300, and HFCP.

Example 4. Distillation Analysis of Composition 4

[0085] The process of Example 3 was repeated for Composition 4 (75.5% t-DCE, 2.6% HFE-7300, and 21.9% HFCP). The results of the fractional distillation of the ternary azeotrope-like Composition 4 are listed in Table 5 below.

[0086]

Table 5.

Component	Initial	10%	20%	40%	50%	50% Heel
t-DCE	75.5%	79.1%	78.8%	78.6%	78.6%	71.0%
HFE-7300	2.6%	2.7%	2.6%	2.5%	2.5%	2.7%
HFCP	21.9%	18.2%	18.6%	18.9%	18.9%	26.3%

[0087] Table 6 shows the boiling point and dew point through distillation of Composition 4.

Table 6.

	Initial	10%	20%	40%	50%
BP (°C)	46.5	46.9	46.9	46.9	46.9
DP (°C)	45	46	46	46	46

[0088] Throughout the distillation of Composition 4, the boiling temperatures and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7300, and HFCP.

Example 5. Distillation Analysis of Composition 5

[0089] The process of Example 3 was repeated for Composition 5 (91.7% t-DCE, 4.1% HFE-7300, and 4.2% HFCP). The results of the fractional distillation of the ternary azeotrope-like Composition 5 are listed in Table 7 below.

Table 7.

	Initial	15%	25%	40%	50%	50% Heel
t-DCE	91.7%	87.4%	87.9%	88.4%	89.2%	95.5%
HFE-7300	4.1%	6.8%	6.5%	6.1%	5.6%	1.7%
HFCP	4.2%	5.8%	5.6%	5.5%	5.2%	2.8%

[0090] Table 8 shows the boiling point and dew point through distillation of Composition 5.

Table 8.

	Initial	15%	25%	40%	50%
BP (°C)	46.9	47.1	47.3	47.3	47.4
DP (°C)	46	46	46.5	46.5	46.5

[0091] Throughout the distillation of Composition 5, the boiling temperatures and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7300, and HFCP.

Example 6. Distillation Analysis of Composition 6

[0092] The process of Example 3 was repeated for Composition 6 (65.2% t-DCE, 17.4% HFE-7300, and 17.4% HFCP). The results of the fractional distillation of the ternary azeotrope-like Composition 6 was listed in Table 9 below.

Table 9.

	Initial	10%	25%	40%	50%	Heel
t-DCE	65.2%	74.9%	74.7%	74.20%	73.70%	49.2%
HFE-7300	17.4%	11.9%	11.9%	12.10%	12.40%	26.9%
HFCP	17.4%	13.2%	13.4%	13.70%	13.90%	23.9%

[0093] Table 10 shows the boiling point and dew point through distillation of Composition 6.

Table 10.

	Initial	10%	25%	40%	50%
BP (°C)	46.8	47.1	47.1	47.3	47.5
DP (°C)	46	46.5	46.5	47	47

[0094] Throughout the distillation, the boiling temperatures and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7300, and HFCP.

Example 7. Distillation Analysis of Composition 7

[0095] Composition 7 (79.85% t-DCE, 9.95% HFE-7300, and 10.19% HFCEP) was prepared and distilled at atmospheric pressure using a 25 plate Oldershaw distillation column to determine the preferred azeotropic composition. Each mixture was allowed to reflux through the distillation column for one hour, and the first 1% fraction was collected and analyzed for composition via GC/FID. Table 11 shows the results from the 25 plate Oldershaw distillation of composition.

Table 11.

Component	Initial Composition	Distillate Composition
t-DCE	79.85%	79.04%
HFE-7300	9.95%	12.03%
HFCEP	10.19%	8.94%
BP (°C)	47.6	

Example 8. Distillation Analysis of Composition 8

[0096] The process of Example 7 was repeated for Composition 8 (78.1% t-DCE, 14.1% HFE-7300, and 7.8% HFCEP). Table 12 shows the results from the 25 plate Oldershaw distillation of composition.

Table 12.

Component	Initial Composition	Distillate Composition
t-DCE	78.1%	79.0%
HFE-7300	14.1%	13.1%
HFCEP	7.8%	7.9%
BP (°C)	47.6	

[0097] As shown in Tables 11 and 12, distillation of mixtures of t-DCE, HFE-7300, and HFCEP with different starting compositions converged on a narrow range of distillate compositions indicating azeotropic behavior.

Example 9. Distillation Analysis of Composition 9

[0098] Composition 9 (70.0% t-DCE, 15.1% HFE-7200, and 14.8% HFCP) was prepared and distilled at atmospheric pressure using a single-plate distillation apparatus. The mixture was distilled to 50% by weight, and each fraction was taken and analyzed to determine whether the mixture formed a ternary azeotrope-like composition. Each fraction was analyzed via GC/FID, and the boiling point and dew point were recorded at each fraction. The results of the fractional distillation of the ternary azeotrope-like composition are listed in Tables 13 and 14 below.

Table 13.

Component	Initial	10%	20%	40%	50%	50% Heel
t-DCE	70.0%	73.2%	73.1%	73.2%	72.8%	65.6%
HFE-7200	15.1%	15.3%	15.3%	15.1%	15.2%	15.3%
HFCP	14.8%	11.5%	11.5%	11.7%	12.0%	19.3%

Table 14.

	Initial	10%	20%	40%	50%
BP (°C)	46.3	46.3	46.3	46.4	46.4
DP (°C)	45.5	45.5	45.5	46	46

[0099] Throughout the distillation of Composition 9, the boiling temperature and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7200, and HFCP.

Example 10. Distillation Analysis of Composition 10

[0100] The process of Example 9 was repeated for Composition 10 (85.5% t-DCE, 9.5% HFE-7200, and 5.0% HFCP). The results of the fractional distillation of the ternary azeotrope-like composition are listed in Tables 15 and 16 below.

Table 15.

Component	Initial	10%	20%	30%	40%	50%	50% heel
t-DCE	85.5%	79.9%	80.2%	80.5%	81.1%	81.6%	90.5%
HFE-7200	9.5%	14.5%	14.2%	13.9%	13.3%	12.8%	5.3%
HFCP	5.0%	5.6%	5.6%	5.6%	5.6%	5.7%	4.2%

Table 16.

	Initial	10%	20%	30%	40%	50%
BP (°C)	45.8	46	46.1	46.2	46.2	46.2
DP (°C)	45.5	45.5	45.5	46	46	46

[0101] Throughout the distillation of Composition 10, the boiling temperature and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7200, and HFCP.

Example 11. Distillation Analysis of Composition 11

[0102] The process of Example 9 was repeated for Composition 11 (64.6% t-DCE, 33.2% HFE-7200, and 2.2% HFCP). The results of the fractional distillation of the ternary azeotrope-like composition are listed in Tables 17 and 18 below.

Table 17.

Component	Initial	10%	20%	30%	40%	50%	50% heel
t-DCE	64.6%	69.0%	68.7%	68.7%	68.6%	68.3%	56.1%
HFE-7200	33.2%	29.3%	29.6%	29.6%	29.7%	29.9%	41.1%
HFCP	2.2%	1.7%	1.7%	1.7%	1.7%	1.8%	2.8%

Table 18.

	Initial	10%	20%	30%	40%	50%
BP (°C)	46.2	46.3	46.2	46.5	46.5	46.6
DP (°C)	45.5	45.5	45.5	46	46	46

[0103] Throughout the distillation of Composition 11, the boiling temperature and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7200, and HFCP.

Example 12. Distillation Analysis of Composition 12

[0104] Composition 12 (81.30% t-DCE, 3.80% MPHE, and 14.90% HFE-7300) was prepared and distilled at atmospheric pressure using a single-plate distillation apparatus. The mixture was distilled to 45% by weight, and each fraction was taken and analyzed to determine whether the mixture formed a ternary azeotrope-like composition. Each fraction was analyzed via GC/FID, and the boiling point and dew point were recorded at each fraction. The results of the fractional distillation of the ternary azeotrope-like composition are listed in Tables 19 and 20 below.

Table 19.

Component	Initial	15%	30%	45%	55% heel
t-DCE	81.30%	81.80%	81.80%	82.00%	80.60%
HFE-7300	14.90%	16.60%	16.40%	16.20%	13.60%
MPHE	3.80%	1.60%	1.80%	1.80%	5.80%

Table 20.

	Initial	15%	30%	45%
BP (°C)	47.00	47.1	47.1	47
DP (°C)	46.00	46	46	46

[0105] Throughout the distillation of Composition 12, the boiling temperature and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7300, and MPHE.

Example 13. Distillation Analysis of Composition 13

[0106] The process of Example 12 was repeated for Composition 13 (75.0% t-DCE, 5.9% MPHE, and 19.1% HFE-7300). The results of the fractional distillation of the ternary azeotrope-like composition are listed in Tables 21 and 22 below.

Table 21.

Component	Initial	10%	20%	30%	40%	50%	50% heel
t-DCE	75.0 %	80.80 %	80.60 %	80.50 %	80.60 %	80.60 %	66.60%
HFE 7300	19.1 %	17.10 %	17.10 %	17.20 %	17.10 %	16.90 %	22.20%
MPHE	5.9%	2.1%	2.3%	2.3%	2.3%	2.5%	11.2%

Table 22.

	Initial	10%	20%	30%	40%	50%
BP (°C)	45.7	45.8	45.8	45.8	46	46
DP (°C)	45.5	45.5	45.5	4.5	45.5	45.5

[0107] Throughout the distillation of Composition 13, the boiling temperature and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7300, and MPHE.

Example 14. Distillation Analysis of Composition 14

[0108] The process of Example 12 was repeated for Composition 14 (90.20% t-DCE, 3.30% MPHE, and 6.60% HFE-7300). The results of the fractional distillation of the ternary azeotrope-like composition are listed in Tables 22 and 23 below.

Table 22.

Component	Initial	15%	30%	45%	60%	40% heel
t-DCE	90.20%	87.95%	88.81%	88.24%	89.09%	92.75%
HFE-7300	6.60%	10.12%	9.18%	9.54%	8.66%	2.35%
MPHE	3.30%	1.93%	2.01%	2.22%	2.25%	4.89%

Table 23.

	Initial	15%	30%	45%	60%
BP (°C)	47.0	47.1	47.1	47	47.3
DP (°C)	46.0	46	46	46	46.5

[0109] Throughout the distillation of Composition 14, the boiling temperature and compositions remained constant, indicating azeotropic behavior of ternary mixtures of t-DCE, HFE-7300, and MPHE.

Example 15. Cleaning Effectiveness Factor (CEF) Analysis of Composition 15

[0110] Composition 15 (70% t-DCE, 15% HFCP, and 15% HFE-7200) was decanted into a 1000 mL beaker with a condensing coil and heated to the boiling point (45.5 °C) using a hot plate. Three precleaned 304 stainless steel coupons were weighed on an analytical balance (initial weight). A thin film of each grease or oil was applied to one surface of each coupon and excess was removed with a wipe. Each coupon was then reweighed to determine the soiled weight and subsequently placed in the vapor phase of the boiling composition for ten minutes. The coupons were then removed and allowed to dry and off-gas for ten minutes before reweighing (post cleaning weight) to determine the cleaning effectiveness factor of the solvent blend. Results of the cleaning analysis are shown in Table 24, and the CEF was determined according to Equation 1.

Equation 1.

$$\text{CEF} = (\text{soiled weight} - \text{post cleaning weight}) / (\text{soiled weight} - \text{initial weight})$$

Table 24.

Coupon	Contaminant	Initial weight (g)	Soiled weight (g)	Post-cleaned weight (g)	CEF (% removed)
1	MobilGrease 28	19.9935	20.211	19.994	99.8%
2	Chesterton AWC cutting oil	19.9927	20.0301	19.993	99.2%
3	DC-200 silicone oil	19.9935	20.049	19.9939	99.3%

Example 16. Cleaning Effectiveness Factor (CEF) Analysis of Composition 16

[0111] The process in Example 15 was repeated for Composition 16 (92% t-DCE, 4% HFE-7300, and 4% HFCEP) using different contaminants, and the results are listed below in Table 25.

Table 25.

Coupon	Contaminant	Initial weight (g)	Soiled weight (g)	Post-cleaned weight (g)	CEF (% removed)
1	Stacking wax #4 from Universal photonics	19.9947	20.151	19.9948	99.9%
2	mineral oil	19.9948	20.0887	19.9948	100.0%
3	DC-44 Silicone bearing grease	19.9948	20.0518	19.9974	95.4%

[0112] As shown in Tables 24 and 25, both ternary compositions were highly effective in removing a wide range of greases, oils, and waxes using only vapor-phase cleaning typically used in a vapor degreaser.

OTHER EMBODIMENTS

[0113] 1. In some embodiments, the present application provides a composition, comprising:

- i) trans-1,2-dichloroethylene;
- ii) a second component which is a hydrofluoroether;
- iii) a third component selected from a compound selected from a hydrofluorocarbon and alkyl perfluoroalkene ether.

[0114] 2. The composition of embodiment 1, wherein the composition does not further comprise a compound selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate.

- [0115]** 3. The composition of embodiment 1, wherein the composition does not further comprise a compound selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate.
- [0116]** 4. The composition of any one of embodiments 1-3, which is an azeotrope composition.
- [0117]** 5. The composition of any one of embodiments 1-3, which is an azeotrope-like composition.
- [0118]** 6. The composition of any one of embodiments 1-5, wherein the hydrofluoroether is selected from HFE-7000, HFE-7100, HFE-7200, HFE-7300, and HFE-347pc-f.
- [0119]** 7. The composition of any one of embodiments 1-5, wherein the hydrofluoroether is selected from HFE-7200 and HFE-7300.
- [0120]** 8. The composition of embodiment 6 or 7, wherein the composition comprises about 5 weight percent to about 45 weight percent HFE-7200.
- [0121]** 9. The composition of embodiment 6 or 7, wherein the composition comprises about 1 weight percent to about 30 weight percent HFE-7300.
- [0122]** 10. The composition of any one of embodiments 1-10, wherein the third component is a hydrofluorocarbon.
- [0123]** 11. The composition of embodiment 10, wherein the hydrofluorocarbon is selected from heptafluorocyclopentane, pentafluorobutane, and pentafluoropropane.
- [0124]** 12. The composition of embodiment 10 or 11, wherein the hydrofluorocarbon is selected from 1,1,2,2,3,3,4-heptafluorocyclopentane, 1,1,1,3,3-pentafluorobutane, and 1,1,1,3,3-pentafluoropropane.

- [0125]** 13. The composition of any one of embodiments 10-12, wherein the hydrofluorocarbon is 1,1,2,2,3,3,4-heptafluorocyclopentane.
- [0126]** 14. The composition of embodiment 12 or 13, wherein the composition comprises about 1 weight percent to about 30 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
- [0127]** 15. The composition of any one of embodiments 1-10, wherein the third component is an alkyl perfluoroalkene ether.
- [0128]** 16. The composition of embodiment 15, wherein the alkyl perfluoroalkene ether is methyl perfluoroheptene ether.
- [0129]** 17. The composition of embodiment 16, wherein the methyl perfluoroheptene ether comprises a mixture of about 50 weight percent 5-methoxy perfluoro-3-heptene, about 20 weight percent 3-methoxy perfluoro-3-heptene, about 20 weight percent 4-methoxy perfluoro-2-heptene, and about 8 weight percent 4-methoxy perfluoro-3-heptene.
- [0130]** 18. The composition of embodiment 16 or 17, wherein the composition comprises about 1 weight percent to about 5 weight percent methyl perfluoroheptene ether.
- [0131]** 19. The composition of any one of embodiments 1-18, wherein the composition comprises about 65 weight percent to about 98 weight percent trans-1,2-dichloroethylene.
- [0132]** 20. The composition of any one of embodiments 1-7, 9-14, and 19, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7300, and heptafluorocyclopentane.
- [0133]** 21. The composition of any one of embodiments 1-7, 9-14, 19, and 20, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7300, and 1,1,2,2,3,3,4-heptafluorocyclopentane.

- [0134]** 22. The composition of any one of embodiments 1-7, 9-14, and 19-21, wherein the composition comprises:
- i) about 75 weight percent to about 90 weight percent trans-1,2-dichloroethylene;
 - ii) about 1 weight percent to about 20 weight percent HFE-7300;
- and
- iii) about 1 weight percent to about 20 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
- [0135]** 23. The composition of any one of embodiments 1-8, 10-14, and 19, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7200, and heptafluorocyclopentane.
- [0136]** 24. The composition of any one of embodiments 1-8, 10-14, 19, and 23, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7200, and 1,1,2,2,3,3,4-heptafluorocyclopentane.
- [0137]** 25. The composition of any one of embodiments 1-8, 10-14, 19, 23 and 24, wherein the composition comprises:
- i) about 65 weight percent to about 85 weight percent trans-1,2-dichloroethylene;
 - ii) about 10 weight percent to about 30 weight percent HFE-7200;
- and
- iii) about 1 weight percent to about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
- [0138]** 26. The composition of any one of embodiments 1-7, 9, and 15-19, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7300, and methyl perfluoroheptene ether.
- [0139]** 27. The composition of any one of embodiments 1-7, 9, 15-19, and 26, wherein the composition comprises:

- i) about 75 weight percent to about 90 weight percent trans-1,2-dichloroethylene;
 - ii) about 5 weight percent to about 20 weight percent HFE-7300;
- and
- iii) about 1 weight percent to about 5 weight percent methyl perfluoroheptene ether.

[0140] 28. The composition of any one of embodiments 1-7, 9-14, and 19-22, comprising:

- i) about 79 weight percent trans-1,2-dichloroethylene;
- ii) about 12 weight percent HFE-7300; and
- iii) about 9 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0141] 29. The composition of any one of embodiments 1-8, 10-14, 19, and 23-25, comprising:

- i) about 73 weight percent trans-1,2-dichloroethylene;
- ii) about 23 weight percent HFE-7200; and
- iii) about 4 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0142] 30. The composition of any one of embodiments 1-8, 10-14, 19, and 23-25, comprising:

- i) about 70 weight percent trans-1,2-dichloroethylene;
- ii) about 15 weight percent HFE-7200; and
- iii) about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.

[0143] 31. In some embodiments, the present application further provides a method for removing at least a portion of residue from the surface of a substrate comprising contacting the substrate with the composition of any one of embodiments 1-30.

[0144] 32. The method of embodiment 31, wherein the composition further comprises a propellant.

[0145] 33. The method of embodiment 32, wherein the propellant is air, nitrogen, carbon dioxide, 2,3,3,3-tetrafluoropropene, trans-1,3,3,3-tetrafluoropropene, 1,2,3,3,3-pentafluoropropene, difluoromethane, trifluoromethane, difluoroethane, trifluoroethane, tetrafuloroethane, pentafluoroethane, hydrocarbons, dimethyl ether, or any mixture thereof.

[0146] 34. The method of any one of embodiments 31-33, wherein the composition further comprises a surfactant.

[0147] 35. The method of any one of embodiments 31-34, wherein said contacting is accomplished by vapor degreasing.

[0148] 36. The method of embodiment 35, wherein the vapor degreasing is performed by boiling the composition to form vapors of said composition and exposing at least a portion of residue from the surface of a substrate to said vapors.

[0149] 37. The method of any one of embodiments 31-34, wherein said contacting is accomplished by immersing the substrate in the composition.

[0150] 38. The method of embodiment 37, wherein the composition is at a temperature greater than ambient temperature or room temperature.

[0151] 39. The method of embodiment 37, wherein the composition is at a temperature of about the boiling point of the composition.

[0152] 40. The method of any one of embodiments 37-39, further comprising a second immersion of the substrate in the composition, wherein said composition is at a temperature lower than the temperature of the first immersing step.

[0153] 41. The method of embodiment 40, wherein the composition in the second immersing step is at ambient temperature or room temperature.

[0154] 42. The method of any one of embodiments 31-41, wherein the substrate is selected from stainless steel and magnetic disk media.

[0155] 43. The method of any one of embodiments 31-42, wherein the residue is selected from flux, lubricant, grease, oil, wax, and combination thereof.

[0156] 44. In some embodiments, the present application further provides a process for dissolving a solute, comprising contacting and mixing said solute with a sufficient quantity of the composition of any one of embodiments 1-30.

[0157] 45. In some embodiments, the present application further provides a process of cleaning a surface, comprising contacting the composition of any one of embodiments 1-30 with said surface.

[0158] 46. In some embodiments, the present application further provides a process for removing at least a portion of water from the surface of a wetted substrate, comprising contacting the substrate with the composition of any one of embodiments 1-30, and then removing the substrate from contact with the composition.

[0159] 47. The process of embodiment 46, wherein composition further comprises at least one surfactant suitable for dewatering or drying the substrate.

[0160] 48. In some embodiments, the present application further provides a process of depositing a fluorolubricant on a surface, comprising:

a) combining a fluorolubricant and a solvent to form a lubricant-solvent combination, wherein the solvent comprises a composition of any one of embodiments 1-30;

b) contacting the lubricant-solvent combination with the surface;
and

c) evaporating the solvent from the surface to form a fluorolubricant coating on the surface.

[0161] It is to be understood that while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims. It should be appreciated by those persons having ordinary skill in the art(s) to which the present invention relates that any of the features described herein in respect of any particular aspect and/or embodiment of the present invention can be combined with one or more of any of the other features of any other aspects and/or embodiments of the present invention described herein, with modifications as appropriate to ensure compatibility of the combinations. Such combinations are considered to be part of the present invention contemplated by this disclosure.

WHAT IS CLAIMED IS:

1. A composition, comprising:
 - i) trans-1,2-dichloroethylene;
 - ii) a second component which is a hydrofluoroether;
 - iii) a third component selected from a compound selected from a hydrofluorocarbon and alkyl perfluoroalkene ether.
2. The composition of claim 1, wherein the composition does not further comprise a compound selected from a C₁₋₆ alcohol, a C₃₋₆ ketone, a C₅₋₈ alkane, a C₃₋₆ cycloalkane, and a C₁₋₆ alkyl acetate.
3. The composition of claim 1, wherein the composition does not further comprise a compound selected from methanol, ethanol, isopropanol, acetone, n-hexane, cyclopentane, and ethyl acetate.
4. The composition of claim 1, which is an azeotrope composition.
5. The composition of claim 1, which is an azeotrope-like composition.
6. The composition of claim 1, wherein the hydrofluoroether is selected from HFE-7000, HFE-7100, HFE-7200, HFE-7300, and HFE-347pc-f.
7. The composition of claim 1, wherein the hydrofluoroether is selected from HFE-7200 and HFE-7300.
8. The composition of claim 7, wherein the composition comprises about 5 weight percent to about 45 weight percent HFE-7200.
9. The composition of claim 7, wherein the composition comprises about 1 weight percent to about 30 weight percent HFE-7300.

10. The composition of claim 1, wherein the third component is a hydrofluorocarbon.
11. The composition of claim 10, wherein the hydrofluorocarbon is selected from heptafluorocyclopentane, pentafluorobutane, and pentafluoropropane.
12. The composition of claim 10, wherein the hydrofluorocarbon is selected from 1,1,2,2,3,3,4-heptafluorocyclopentane, 1,1,1,3,3-pentafluorobutane, and 1,1,1,3,3-pentafluoropropane.
13. The composition of claim 10, wherein the hydrofluorocarbon is 1,1,2,2,3,3,4-heptafluorocyclopentane.
14. The composition of claim 13, wherein the composition comprises about 1 weight percent to about 30 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
15. The composition of claim 1, wherein the third component is an alkyl perfluoroalkene ether.
16. The composition of claim 15, wherein the alkyl perfluoroalkene ether is methyl perfluoroheptene ether.
17. The composition of claim 16, wherein the methyl perfluoroheptene ether comprises a mixture of about 50 weight percent 5-methoxy perfluoro-3-heptene, about 20 weight percent 3-methoxy perfluoro-3-heptene, about 20 weight percent 4-methoxy perfluoro-2-heptene, and about 8 weight percent 4-methoxy perfluoro-3-heptene.
18. The composition of claim 16, wherein the composition comprises about 1 weight percent to about 5 weight percent methyl perfluoroheptene ether.

19. The composition of claim 1, wherein the composition comprises about 65 weight percent to about 98 weight percent trans-1,2-dichloroethylene.
20. The composition of claim 1, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7300, and heptafluorocyclopentane.
21. The composition of claim 1, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7300, and 1,1,2,2,3,3,4-heptafluorocyclopentane.
22. The composition of claim 1, wherein the composition comprises:
- i) about 75 weight percent to about 90 weight percent trans-1,2-dichloroethylene;
 - ii) about 1 weight percent to about 20 weight percent HFE-7300; and
 - iii) about 1 weight percent to about 20 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
23. The composition of claim 1, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7200, and heptafluorocyclopentane.
24. The composition of claim 1, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7200, and 1,1,2,2,3,3,4-heptafluorocyclopentane.
25. The composition of claim 1, wherein the composition comprises:
- i) about 65 weight percent to about 85 weight percent trans-1,2-dichloroethylene;
 - ii) about 10 weight percent to about 30 weight percent HFE-7200; and
 - iii) about 1 weight percent to about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
26. The composition of claim 1, wherein the composition comprises trans-1,2-dichloroethylene, HFE-7300, and methyl perfluoroheptene ether.

27. The composition of claim 1, wherein the composition comprises:
- i) about 75 weight percent to about 90 weight percent trans-1,2-dichloroethylene;
 - ii) about 5 weight percent to about 20 weight percent HFE-7300; and
 - iii) about 1 weight percent to about 5 weight percent methyl perfluoroheptene ether.
28. The composition of claim 1, comprising:
- i) about 79 weight percent trans-1,2-dichloroethylene;
 - ii) about 12 weight percent HFE-7300; and
 - iii) about 9 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
29. The composition of claim 1, comprising:
- i) about 73 weight percent trans-1,2-dichloroethylene;
 - ii) about 23 weight percent HFE-7200; and
 - iii) about 4 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
30. The composition of claim 1, comprising:
- i) about 70 weight percent trans-1,2-dichloroethylene;
 - ii) about 15 weight percent HFE-7200; and
 - iii) about 15 weight percent 1,1,2,2,3,3,4-heptafluorocyclopentane.
31. A method for removing at least a portion of residue from the surface of a substrate comprising contacting the substrate with the composition of claim 1.
32. The method of claim 31, wherein the composition further comprises a propellant.
33. The method of claim 32, wherein the propellant is air, nitrogen, carbon dioxide, 2,3,3,3-tetrafluoropropene, trans-1,3,3,3-tetrafluoropropene, 1,2,3,3,3-

pentafluoropropene, difluoromethane, trifluoromethane, difluoroethane, trifluoroethane, tetrafluoroethane, pentafluoroethane, hydrocarbons, dimethyl ether, or any mixture thereof.

34. The method of claim 33, wherein the composition further comprises a surfactant.

35. The method of claim 33, wherein said contacting is accomplished by vapor degreasing.

36. The method of claim 35, wherein the vapor degreasing is performed by boiling the composition to form vapors of said composition and exposing at least a portion of residue from the surface of a substrate to said vapors.

37. The method of claim 31, wherein said contacting is accomplished by immersing the substrate in the composition.

38. The method of claim 37, wherein the composition is at a temperature greater than ambient temperature or room temperature.

39. The method of claim 37, wherein the composition is at a temperature of about the boiling point of the composition.

40. The method of claim 37, further comprising a second immersion of the substrate in the composition, wherein said composition is at a temperature lower than the temperature of the first immersing step.

41. The method of claim 40, wherein the composition in the second immersing step is at ambient temperature or room temperature.

42. The method of claim 31, wherein the substrate is selected from stainless steel and magnetic disk media.
43. The method of claim 31, wherein the residue is selected from flux, lubricant, grease, oil, wax, and combination thereof.
44. A process for dissolving a solute, comprising contacting and mixing said solute with a sufficient quantity of the composition of claim 1.
45. A process of cleaning a surface, comprising contacting the composition of claim 1 with said surface.
46. A process for removing at least a portion of water from the surface of a wetted substrate, comprising contacting the substrate with the composition of claim 1, and then removing the substrate from contact with the composition.
47. The process of claim 46, wherein composition further comprises at least one surfactant suitable for dewatering or drying the substrate.
48. A process of depositing a fluorolubricant on a surface, comprising:
- a) combining a fluorolubricant and a solvent to form a lubricant-solvent combination, wherein the solvent comprises a composition of claim 1;
 - b) contacting the lubricant-solvent combination with the surface; and
 - c) evaporating the solvent from the surface to form a fluorolubricant coating on the surface.