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(54) **Title:** FLUOROALKYLSILANES AND COATINGS THEREFROM

(57) **Abstract:** Novel fluoroalkylsilanes of the following formula are described; $R_f-O-CH_2CF_2-O-(CH_2)_n-Si(R)_xX_{3-x}$, wherein R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain -Q-, -S- or -NR¹ - heteroatoms, where R_f^1 is a perfluoroalkyl; X is a hydrolysable group; R is a C₁C₄ alkyl group; n is at least 3; and x is 1 to 3.



FLUOROALKYLSILANES AND COATINGS THEREFROM

FIELD

This invention relates to methods of treating substrates (especially substrates having a hard surface such as, for example, ceramics or glass) to impart water, oil, stain, and/or dirt repellency to a surface thereof, and, in other aspects, this invention relates to compositions for use in the methods and to substrates treated thereby.

Background

Various fluorochemical compositions have been used as coating compositions for application to substrates (for example, hard surface substrates and fibrous substrates) to impart low surface energy characteristics such as oil and/or water repellency (oleophobicity and/or hydrophobicity). When used in coatings or films, however, many fluorochemical materials have tended to diffuse to the surface of the coating or film and to become depleted over time (for example, due to repeated cleanings of the surface). This has led to the use of fluorochemical derivatives having reactive or functional groups (for example, perfluoropolyether thiols, silanes, phosphates, and acrylates) to enable covalent attachment to the coatings, films, or substrate surfaces.

Silane compounds having one or more fluorochemical groups have been used (alone and in combination with other materials) to prepare surface treatment compositions for substrates such as glass and ceramics. Such silane compounds have typically included one or more hydrolyzable groups and at least one polyfluorinated alkyl or polyether group.

Numerous fluorochemical surface treatments have been developed and have varied in their ease of applicability to substrates (for example, due to differences in viscosity and/or in solvent solubilities, some treatments even requiring expensive vapor deposition or multiple application steps), in their requisite curing conditions (for example, some requiring relatively high curing temperatures for relatively long periods of time), in their repellency levels, in their ease of cleaning, in their degrees of optical clarity, and/or in their durability (for example, in their chemical resistance, abrasion resistance, and/or solvent

resistance). Many have also been at least somewhat substrate-specific, requiring production of multiple compositions to ensure adhesion to different substrates.

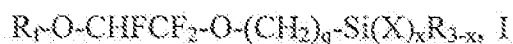
SUMMARY

Thus, we recognize that there exists an ongoing need for surface treatment processes (and fluorochemical compositions for use therein) that can meet the performance requirements of a variety of different surface treatment applications. Such processes will preferably be simple, cost-effective, compatible with existing manufacturing methods, and/or capable of imparting repellency (preferably, durable, tailored repellency) to a variety of different substrates.

Briefly, in one aspect, this invention provides a novel fluoroalkylsilane. In another aspect this disclosure provides a coating composition comprising the fluoroalkylsilane with high water repellency, as measure by the receding water contact angle. In another aspect this disclosure provides a practical process for making the fluoroalkylsilane with unique space linkage group. In another aspect, this disclosure provide a surface treatment process which comprises (a) providing at least one substrate having at least one major surface; coating the surface with the coating composition, and curing the coating. In another aspect this disclosure provides the coated articles which have high water contact angles, especially receding water repellency.

Detailed Description

This disclosure provides fluoroalkylsilanes of the formula:



wherein

R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain -O-, -S- or -NR_f¹- heteroatoms, where R_f^1 is a perfluoroalkyl, preferably a C₁-C₆ perfluoroalkyl;

X is a hydrolysable group;

R is an alkyl group or an aryl group;

q is at least 3; and

x is 1 to 3.

The R_f groups may be linear or branched and of the formula:

$C_nF_{2n+1}-$, where n is at least 1, preferably at least 3, more preferably 3-6; or may be $C_nF_{2n+1}-(O-C_mF_{2m})_p-$, where n is at least 1, m is at least 2, and p may be a number from 1 to 10;

or $C_nF_{2n+1}N(C_oF_{2o+1})-C_mF_{2m}-$, where n is at least 1, o is at least 1 and m is at least 2.

5 Preferably, each of the perfluoroalkyl or perfluoroalkylene groups (e.g. $C_nF_{2n+1}-$, C_oF_{2o+1} or $-C_mF_{2m}-$) are selected from C_3-C_8 .

It has been reported that certain perfluorooctyl-containing compounds ($C_8F_{17}-$) may tend to bio-accumulate in living organisms; this tendency has been cited as a potential concern regarding some fluorochemical compositions. For example, see U.S. 5,688,884
 10 (Baker et al.). As a result, there is a desire for fluorine-containing compositions effective in providing desired functional properties, e.g., water- and oil-repellency, surfactant properties, etc. while eliminating more effectively from biological systems. However, it has also been asserted that only perfluoroalkyl groups of the formula $F(CF_2)_n-$ have six or greater carbons have the self-alignment capability to achieve useful performance, while
 15 shorter chains, e.g. C_4F_9- lack the self-alignment necessary for good performance. See Phillips and Dettree, J.Col and Interface Sci., vol. 56(2), August 1976.

Therefore it remains a challenge to provide shorter chain perfluoroalkyl compositions that are less bioaccumulative, while maintain the requisite performance.

In some preferred embodiments, the present fluoroalkylsilane compounds and
 20 coating compositions provide the necessary performance even with the shorter C_3-C_6 perfluoroalkyl groups. Furthermore, the short chain perfluorocarboxylic acids (the presumed intermediate degradation products) are less toxic and less bioaccumulative than the longer chain (C_8) homologues. For these reasons, the R_f groups is preferably selected from C_3-C_6 perfluoroalkyl (and/or perfluoroalkylene) groups.

25 In some preferred embodiments, n is at least 6, i.e at least a $-C_6H_{12}-$ alkylene. It has been observed that excellent repellency is achieved when the spacer alkylene is at least six carbons, as measured by the receding contact angle.

The X groups can be the same or different and are capable of hydrolyzing, for example, in the presence of water, optionally under acidic or basic conditions, to produce
 30 groups capable of undergoing a condensation reaction (for example, hydroxysilyl groups). Desirably, each X is independently selected from hydroxyl, halogen, alkoxy, acyloxy,

aryloxy, and combinations thereof; most desirably, each X is independently alkoxy). It will be appreciated that the X groups will hydrolyze in the presence of water or moisture, and some portion of the X groups may be hydrolyzed to -OH groups, which may then form siloxane linkages with each other or with hydroxyl-containing substrate surface via dehydration condensation reactions.

In some preferred embodiments, alkoxy is $-OR^3$, and acyloxy is $-OC(O)R^3$, wherein each R^3 is independently a lower alkyl group (C_1 - C_6). For certain embodiments, R^3 is preferably C_{1-6} alkyl and more preferably C_{1-4} alkyl. R^3 can be a linear or branched alkyl group. In some preferred embodiments, aryloxy is $-OR^4$, wherein R^4 is aryl, optionally comprising one or more substituents independently selected C_{1-4} alkyl. For certain embodiments, R^4 is preferably unsubstituted or substituted C_{6-12} aryl.

Preferred fluoroalkylsilanes include those where R_f is a short (C_1 - C_6) perfluoroalkyl and perfluoroalkoxyalkyl group, q is 6 or greater and X is selected from Cl, OCH_3 , OCH_2CH_3 , $OCH_2CH_2CH_3$ or $OCH(CH_3)_2$. The preferred R_f is selected from CF_3 , CF_3CF_2 , $n-C_3F_7$ and $CF_3OCF_2CF_2CF_2$.

The compounds of Formula I may be prepared by hydrosilation of a fluorinated compound of the formula:



with a hydrosilane of the formula:



in the presence of a hydrosilation catalyst, where

R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain -O-, -S- or - NR_f^1 - heteroatoms, where R_f^1 is a perfluoroalkyl, preferably a C_1 - C_6 perfluoroalkyl;

X is a hydrolysable group;

R is an alkyl group or an aryl group;

q is at least 3; and

x is 1 to 3.

Numerous patents teach the use of various complexes of cobalt, rhodium, nickel, palladium, or platinum as catalysts for hydrosilylation between a compound containing silicon-bonded hydrogen such as formula III and a compound containing terminal aliphatic unsaturation. For example, U.S. 4,288,345 (Ashby et al) discloses as a catalyst for

hydrosilylation reactions a platinum-siloxane complex. Additional platinum-siloxane complexes are disclosed as catalysts for hydrosilylation reactions in U.S. Pat. Nos. 3,715,334, 3,775,452, and 3,814,730 (Karstedt et al). U.S. 3,470,225 (Knorre et al) discloses production of organic silicon compounds by addition of a compound containing
5 silicon- bonded hydrogen to organic compounds containing at least one non-aromatic double or triple carbon-to-carbon bond using a platinum compound of the empirical formula $PtX_2(RCOCR'COR'')_2$ wherein X is halogen, R is alkyl, R' is hydrogen or alkyl, and R'' is alkyl or alkoxy.

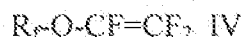
The catalysts disclosed in the foregoing patents are characterized by their high
10 catalytic activity. Other platinum complexes for accelerating the aforementioned thermally-activated addition reaction include: a platinacyclobutane complex having the formula $(PtCl_2C_3H_6)_2$ (U.S. 3,159,662, Ashby); a complex of a platinum salt and an olefin (U.S. 3,178,464, Pierpoint); a platinum-containing complex prepared by reacting chloroplatinic acid with an alcohol, ether, aldehyde, or mixtures thereof (U.S. 3,220,972,
15 Lamoreaux); a platinum compound selected from trimethylplatinum iodide and hexamethyldiplatinum (U.S. 3,313,773, Lamoreaux); a hydrocarbyl or haloalkyl nitrile-platinum (II) halide complex (U.S. 3,410,886, Joy); a hexamethyl-dipyridine-diplatinum iodide (U.S. 3,567,755, Seyfried et al); a platinum curing catalyst obtained from the reaction of chloroplatinic acid and a ketone having up to 15 carbon atoms (U.S.
20 3,814,731, Nitzsche et al); a platinum compound having the general formula $(R')PtX_2$ where R' is a cyclic hydrocarbon radical or substituted cyclic hydrocarbon radical having two aliphatic carbon-carbon double bonds, and X is a halogen or alkyl radical (U.S. 4,276,252, Kreis et al); platinum alkyne complexes (U.S. 4,603,215, Chandra et al.); platinum alkenylcyclohexene complexes (U.S. 4,699,813, Cavezzan); and a colloidal
25 hydrosilylation catalyst provided by the reaction between a silicon hydride or a siloxane hydride and a platinum (0) or platinum (II) complex (U.S. 4,705,765, Lewis).

Although these platinum complexes and many others are useful as catalysts in processes for accelerating the hydrosilation, processes for promoting the ultraviolet or visible radiation-activated addition reaction between these compounds may be preferable
30 in some instances. Platinum complexes that can be used to initiate ultraviolet radiation-activated hydrosilation reactions have been disclosed, e.g., platinum azo complexes (U.S.

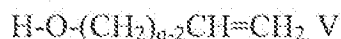
Pat. No. 4,670,531, Eckberg); (η^4 -cyclooctadiene)diarylplatinum complexes (U.S. 4,530,879, Drahnak); and (η^5 -cyclopentadienyl)trialkylplatinum complexes (U.S. 4,510,094, Drahnak). Other compositions that are curable by ultraviolet radiation include those described in U.S. 4,640,939 and 4,712,092 and in European Patent Application No. 0238033. U.S. 4,916,169 (Boardman et al) describes hydrosilylation reactions activated by visible radiation. U.S. 6,376,569 (Oxman et al.) describes a process for the actinic radiation-activated addition reaction of a compound containing silicon-bonded hydrogen with a compound containing aliphatic unsaturation, said addition being referred to as hydrosilylation, the improvement comprising using, as a platinum hydrosilylation catalyst, an (η^5 -cyclopentadienyl)tri(σ -aliphatic)platinum complex, and, as a reaction accelerator, a free-radical photoinitiator capable of absorbing actinic radiation, i.e., light having a wavelength ranging from about 200 nm to about 800 nm. The process can also employ, as a sensitizer, a compound that absorbs actinic radiation, and that is capable of transferring energy to the aforementioned platinum complex or platinum complex/free-radical photoinitiator combination, such that the hydrosilylation reaction is initiated upon exposure to actinic radiation. The process is applicable both to the synthesis of low molecular weight compounds and to the curing of high molecular weight compounds, i.e., polymers.

The preferred hydrosilane of the formula III is selected from H-SiCl_3 , H-Si(OMe)_3 and $\text{H-Si(OCH}_2\text{CH}_3)_3$.

The unsaturation fluoroalkyl compounds of Formula II, in turn, may be prepared by reaction of a compound of the formula:



with a compound of the formula:



in the presence of a base catalyst as described in US20050113609, and where q and R_f are as previously defined.

The perfluorovinyl ether of Formula IV, in turn, may be prepared by fluoride ion catalyzed addition of a perfluorinated acid fluoride to hexafluoropropylene oxide, followed by decarboxylation, according to the techniques describe in US 6255536 (Worm et al.), incorporated herein by reference. Perfluorinated acid fluoride may be obtained from

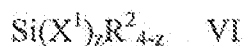
hexafluoropropene oxide by reaction with a metal fluoride. Alternatively, the perfluorinated acid fluorides may be prepared by electrochemical fluorination of alcohols, acids or esters as known in the art, for example as described in US6482979 (Hintzer et al.), incorporated herein by reference.

Commercial available perfluorovinyl ethers of Formula IV are, for example, $\text{CF}_3\text{OCF}=\text{CF}_2$, $\text{CF}_3\text{CF}_2\text{CF}_2\text{OCF}=\text{CF}_2$ and $\text{CF}_3\text{OCF}_2\text{CF}_2\text{OCF}=\text{CF}_2$.

Generally, the coating is formulated in a solvent or mixed solvents for easy use at the concentration of 0.01 to 50 wt%; preferably at 0.1 to 20%.

For crosslink or curing of the coating, moisture is needed, either by addition of limited water to the coating formulation or absorption of moisture from air after coating on substrates. To accelerate the curing, an acid or base catalyst may be optionally presented in the formulation.

In some embodiments, the coating composition may further comprise a crosslinking agent for the fluoroalkylsilane. A class of useful crosslinkers includes compounds that can be represented by the following general formula:



wherein each X^1 is independently hydroxyl, a hydrolyzable group, or a combination thereof; each R^2 is independently a C_1 - C_4 alkyl group; z is an integer of 1, 2, 3 or 4.

Preferences for X^1 and R^2 include those set forth above for the X and R groups of Formula I. The crosslinkers can be included in the surface treatment composition in any of a wide range of amounts (for example, from about 1 to 20 weight percent), depending, for example, upon the particular application and the desired properties. Most preferred are tetraalkoxysilanes, such as commercial available tetraethoxysilane, alone or in a mixture with trialkoxysilanes.

A variety of non-functional inorganic oxide particulate solutions or dispersions can be used in the coating composition. The particles are typically substantially spherical in shape and relatively uniform in size. The particles can have a substantially monodisperse size distribution or a polymodal distribution obtained by blending two or more substantially monodisperse distributions. The inorganic oxide particles are typically non-aggregated (substantially discrete), as aggregation can result in precipitation of the inorganic oxide particles or gelation of the composition.

The inorganic oxide particles are typically colloidal, having an average particle diameter of about 0.001 to about 0.2 micrometers, less than about 0.05 micrometers, and less than about 0.03 micrometers. These size ranges facilitate dispersion of the inorganic oxide particles into the coating composition with desirable surface properties and optical clarity. The average particle size of the inorganic oxide particles can be measured using transmission electron microscopy to count the number of inorganic oxide particles of a given diameter.

Inorganic oxide particles include colloidal silica, colloidal titania, colloidal alumina, colloidal zirconia, colloidal vanadia, colloidal chromia, colloidal iron oxide, colloidal antimony oxide, colloidal tin oxide, and mixtures thereof. The inorganic oxide particles can consist essentially of or consist of a single oxide such as silica, or can comprise a combination of oxides, such as silica and aluminum oxide, or a core of an oxide of one type (or a core of a material other than a metal oxide) on which is deposited an oxide of another type. Silica is a common inorganic particle for general applications.

The inorganic oxide particles are often provided in the form of a sol containing a colloidal dispersion of inorganic oxide particles in liquid media including water and isopropanol as solvent. The sol can be prepared using a variety of techniques and in a variety of forms including hydrosols (where water serves as the liquid medium), organosols (where organic liquids so serve), and mixed sols (where the liquid medium contains both water and an organic liquid), e.g., as described in U.S. 5,648,407 (Goetz et al.); U.S. 5,677,050 (Bilkadi et al.) and U.S. 6,299,799 (Craig et al.), the disclosure of which is incorporated by reference herein. Aqueous sols (e.g. of amorphous silica) can be employed. Sols generally contain at least 2 wt-%, at least 10 wt-%, at least 15 wt-%, at least 25 wt-%, and often at least 35 wt-% colloidal inorganic oxide particles based on the total weight of the fluorosilane in the coating formulation. The amount of colloidal inorganic oxide particle is typically no more than 50 wt-%. Most water is generally removed from the aqueous sols prior to formulating with fluorosilane to prevent premature hydrolysis for sufficient shelf life stability.

The coating composition can be prepared by mixing the inorganic oxide particle solution, and other optional ingredients with the curable fluorosilane composition. The resulting composition after applied to a substrate usually is dried to remove substantially

all of the solvent and/or water from the formulation or generated during the silanol dehydration condensation reaction.

Some embodiments, partially surface-modified inorganic particles, preferably nanoparticles (having an average particle size of less than 100 nanometers) may be used.

5 These particles and nanoparticles are prepared from colloidal materials from the group of silica, zinc oxide, titania, alumina, zirconia, vanadia, chromia, iron oxide, antimony oxide, tin oxide, other colloidal metal oxides, and mixtures thereof, modified such that the particles can be easily formulated or dispersed with fluorosilane formulation; these particles can comprise essentially a single oxide such as silica or can comprise a core of an
10 oxide of one type (or a core of a material) on which is deposited the oxide of another type. The particles have an average particle diameter of 5 to about 1000 nm, preferably less than 100 nanometers, more preferably 10 to 50 nm. Average particle size can be measured using transmission electron microscopy to count the number of particles of a given diameter. Additional examples of suitable colloidal silicas are described in U.S. 5,126,394,
15 incorporated herein by reference. Such particles are described in U.S. 6,353,037, and 6,462,100 (Thunhorst et al.), and U.S. 6,329,058 (Arney et al.) and are incorporated herein by reference. The fluorosilane of formula I may also been used for partial modification of inorganic particles.

The resulting curable coating composition can have a relatively long shelf life in
20 the absence of moisture. The components of the composition can be in the form of relatively viscous liquids that can be used in the surface treatment process of the invention in neat form or, preferably, in admixture with commonly-used solvents (for example, alkyl esters, ketones, alkanes, alcohols, and the like, and mixtures thereof).

In some embodiments, the coating composition further includes at least one organic
25 solvent that can dissolve or suspend at least about 0.1 percent by weight of the fluoroalkylsilane of Formula I and silicate components of Formula VI, based upon the total weight of the surface treatment composition. In some embodiments, it can be desirable that the solvent or mixture of solvents have a solubility for water of at least about 1 percent by weight, and for certain of these embodiments, a solubility for acid of at least about 5
30 percent by weight. When solvent is used, useful concentrations of the components can vary over a wide range (for example, from about 0.01 or 0.1 or 1 to about 90 weight

percent), depending upon the solubility of the components, the application method utilized, the nature of the substrate, and the desired surface treatment characteristics.

Suitable organic solvents for use in the surface treatment composition include aliphatic alcohols such as, for example, methanol, ethanol, and isopropanol; ketones such as acetone and methyl ethyl ketone; esters such as ethyl acetate and methyl formate; ethers such as diethyl ether, diisopropyl ether, methyl t-butyl ether, and dipropylene glycol monomethyl ether (DPM); hydrocarbons solvents such as alkanes, for example, heptane, decane, and other paraffinic solvents; perfluorinated hydrocarbons such as perfluorohexane and perfluorooctane; fluorinated hydrocarbons, such as pentafluorobutane; hydrofluoroethers such as methyl perfluorobutyl ether and ethyl perfluorobutyl ether; and the like; and combinations thereof. Preferred solvents include aliphatic alcohols, perfluorinated hydrocarbons, fluorinated hydrocarbons, hydrofluoroethers, and combinations thereof (more preferably, aliphatic alcohols, hydrofluoroethers, and combinations thereof; most preferably, hydrofluoroethers and combinations thereof).

The coating composition may comprise:

- a) 0.25 to 10 wt.% fluoroalkylsilane of Formula I;
 - b) 0 to 20 wt.% inorganic particular filler;
 - c) 0 to 20 wt.% a silane crosslinker;
 - d) 0 to 10 wt.% of an acid catalyst;
- in an organic solvent.

The coating composition can be used as a fluorochemical surface treatment to impart a degree of hydrophobicity and/or oleophobicity to a variety of substrates.

Substrates suitable for use in the process of the invention (and for preparing the surface-treated articles of the invention) include those having at least one surface comprising a material that is solid and preferably substantially inert to any coating solvent that is used. Preferably, the surface treatment can adhere to the substrate surface through chemical interactions, physical interactions, or a combination thereof (more preferably, a combination thereof).

Suitable substrates can comprise a single material or a combination of different materials and can be homogeneous or heterogeneous in nature. Useful heterogeneous

substrates include coated substrates comprising a coating of a material (for example, a glass or a primer) borne on a physical support (for example, a polymeric film).

Useful substrates include those that comprise wood, glass, minerals (for example, both man-made ceramics such as concrete and naturally-occurring stones such as marble and the like), polymers (for example, polycarbonate, polyester, polyacrylate, and the like),
5 metals (for example, copper, silver, aluminum, iron, chromium, stainless steel, nickel, and the like), metal alloys, metal compounds (for example, metal oxides and the like), leather, parchment, paper, textiles, painted surfaces, and combinations thereof. Preferred substrates include those having siliceous surfaces in either primed or unprimed form.

Preferred substrates include glass, minerals, wood, metals, metal alloys, metal compounds,
10 primed polymers, and combinations thereof (more preferably, glass, minerals, metals, metal alloys, metal compounds, primed polymers, and combinations thereof; most preferably, glass, minerals, and combinations thereof).

Typically the substrate will be chosen based in part on the desired optical and
15 mechanical properties for the intended use. Such mechanical properties typically will include flexibility, dimensional stability and impact resistance. The substrate thickness typically also will depend on the intended use. For most applications, substrate thicknesses of less than about 0.5 mm are preferred, and more preferably about 0.02 to about 0.2 mm. Self-supporting polymeric films are preferred. The polymeric material can
20 be formed into a film using conventional filmmaking techniques such as by extrusion and optional uniaxial or biaxial orientation of the extruded film. The substrate can be treated to improve adhesion between the substrate and the coating layer, e.g., chemical treatment, corona treatment such as air or nitrogen corona, plasma, flame, or actinic radiation. If desired, an optional tie layer or primer can be applied to the substrate and/or coating layer
25 to increase the interlayer adhesion.

For best efficacy, the substrate has a surface with groups capable of forming covalent bonds to the silane groups (for example, hydroxyl groups). In some embodiments, the suitability of the surface of the substrate can be improved by deposition of a primer or by some other physical or chemical surface modification technique. Plasma
30 deposition techniques can be used, if desired.

The coating composition can be applied separately or in combination (preferably, in combination) to at least a portion of at least one major surface of the substrate in essentially any manner (and with essentially any thickness) that can form a useful coating. Useful application methods include coating methods such as dip coating, spin coating, spray coating, wiping, roll coating, brushing, spreading, flow coating, and the like, and combinations thereof.

Typically, the coating composition can be coated on the substrate such that after an optional drying, a monolayer of the surface treatment composition results. Typically, such a monolayer can be from about 0.001 to about 1 micrometer thick (more typically, from about 0.001 to about 0.10 microns thick).

After application to the substrate, the coating can be cured by exposure to heat and/or moisture. Moisture cure can be effected at temperatures ranging from room temperature (for example, about 20°C) up to about 80°C or more. Moisture curing times can range from a few minutes (for example, at the higher temperatures) to hours (for example, at the lower temperatures).

For the preparation of a durable coating, sufficient water typically can be present to cause hydrolysis of the hydrolyzable groups described above, so that condensation to form siloxane (Si-O-Si) groups between the fluoroalkylsilanes of Formula I and also the substrate. The water can be, for example, present in the coating composition, adsorbed on the substrate surface, or in the ambient atmosphere. Typically, sufficient water can be present for the preparation of a durable coating if the coating method is carried out at room temperature in an atmosphere containing water (for example, an atmosphere having a relative humidity of about 30 percent to about 50 percent). Preferably, the coating composition can undergo chemical reaction with the surface of the substrate to form a durable coating through the formation of covalent bonds (including Si-O-Si groups).

Useful moisture curing catalysts for silane compounds are well-known in the art and include organic or inorganic acids (for example, acetic acid, propionic acid, butyric acid, valeric acid, maleic acid, stearic acid, hydrochloric acid, nitric acid, sulfuric acid, phosphoric acid, hydrochloric acid, and the like, and combinations thereof), metal carboxylates, metal acetylacetonate complexes, metal powders, peroxides, metal chlorides, organometallic compounds, and the like, and combinations thereof.

When used, the acid catalysts can be present in amounts ranging from about 0.01 to about 10 weight percent (preferably, from about 0.25 to about 10 weight percent; more preferably, from about 0.25 to about 5 weight percent), based upon the total weight of catalyst and surface treatment composition).

A substrate to be coated can typically be contacted with the coating composition at room temperature (typically from 20°C. to 30°. Alternatively, the coating composition can be applied to substrates that are preheated at a temperature of, for example, between 60°C and 150° C. Following application of the surface treatment composition, the coated substrate can be dried and the resulting coating cured at ambient temperature (for example, about 20 °C to about 30 °C or elevated temperature (for example, at about 40 °C to about 150 °C) for a time sufficient for the curing to take place.

The cured coating may be described by the general formula:

$[R_f^2SiO_{3/2}]_a[SiO_{4/2}]_b[RSiO_{3/2}]_c$, where

R_f^2 is $R_f-O-CHF_2-O-(CH_2)_q-$ and the unit is derived from the fluoroalkylsilane of Formula I where subscript "x" is 3,

$[SiO_{4/2}]$ are units derived from the crosslinking silanes of Formula VI where subscript "z" is 4; $[RSiO_{3/2}]$ are units derived from the crosslinking silanes of Formula VI where subscript "z" is 3, and subscripts a, b and c are numbers corresponding to the weight percents of each unit. It will be appreciated that some siloxane bond formation will form with certain substrates

The curable coating composition can be applied to articles comprising one or more of the above-described substrates and then cured to form surface treatments in the form of crosslinked hardcoats. The hardcoats can exhibit surface and/or bulk properties that can be tailored by varying the degree of crosslinking and by varying the natures and relative amounts of the particulate filler. The hardcoats (with their often outstanding durability, adhesion, and repellency properties) can be widely used for applications requiring durable low surface energy characteristics (for example, anti-graffiti coatings for signs, buildings, transportation vehicles, and the like; easily cleanable and/or anti-smudge coatings for glass, paper, clothes, metals, ceramic tiles, electronic devices, optical devices, and the like; mold release coatings for polymer or composite molding; and the like).

A useful hardcoat coating composition comprises:

- a) 0.5 to 5 wt% fluoroalkylsilane of Formula I;
- b) 1 to 10 wt% nanoparticle silica, and/or
- c) 1 to 10 wt% silane crosslinker.

In general, the method of coating comprises providing a substrate, coating at least a portion of the substrate with the coating composition, optionally drying to remove water and/or solvent, and curing the coating. The resulting coating articles are both oleo- and hydrophobic. In some embodiments the coating exhibits a having a receding water contact angle of at least 80°, or at least 90°.

Examples

Materials:

Allyl alcohol, 4-penten-1-ol, 5-hexen-1-ol and 10-undecen-1-ol are obtained from Aldrich Chemical Company, Milwaukee, WI.

3-Buten-1-ol was obtained from GFS Organic Chemicals, Inc., Columbus, OH.

9-Decen-1-ol was obtained from TCI America, Portland, OR.

CH₃OCH₂CH₂OCH₃ was obtained from GFS Organic Chemicals, Inc. Powell, OH.

Platinum -divinyltetramethyldisiloxane complex in xylene (2.1-2.4% Pt(0)), was obtained from Gelest Inc., Morrisville, PA.

H-Si(OMe)₃ and H-Si(OEt)₃ was obtained from purchased from Aldrich Chemical Company, Milwaukee, WI.

H-SiMe(OMe)₂ was obtained from TCI America, Portland, OR.

H-SiMe₂(OEt), obtained from Alfa Aesar, Waltham, MA.

Isopropyl alcohol (IPA), ethyl alcohol (EtOH) was obtained from EMD, Billerica, MA.

HNO₃ was obtained from VWR International, Radnor, PA.

C₈F₁₇(CH₂)₂Si(OEt)₃ (CFS-1), was obtained from, PCR Inc., Gainesville, FL

C₆F₁₃(CH₂)₂Si(OMe)₃ (CSF-2), was obtained from Gelest, Inc., Morrisville, PA.

C₄F₉(CH₂)₂Si(OMe)₃ (CSF-3), was obtained from Gelest, Inc., Morrisville, PA.

C₄F₉SO₂NMeC₃H₆Si(OMe)₃ (FC-4405, CSF-4), was obtained from 3M Company, St. Paul, MN, and can be prepared as described in U.S. 5,274,159 (Pellerite et al.)

ECC-1000 (CSF-5), perfluoropolyether based disilane, was obtained from 3M Company, St. Paul, MN under trade designation "3M™ Easy Clean Coating ECC-1000".

HFE-7100 was obtained from 3M Company, St. Paul, MN under trade designation "3M™ Novec™ 7100 Engineered Fluid".

TEOS, $\text{Si}(\text{OCH}_2\text{CH}_3)_4$, was obtained from Aldrich Chemical Company, Milwaukee, WI.

Test Methods

Method for Determining Contact Angle

Coated films prepared in Examples and Coated Examples described below were rinsed for 1 minute with hand agitation in an isopropanol (IPA) bath prior to water and hexadecane (HD) contact angles measurements. Measurements were made using a VCA-2500XE video contact angle analyzer (available from AST Products, Billerica, MA). Reported values are the average of at least 3 drops; each drop was measured twice. Drop volumes were 5 μL for static measurements and 1-3 μL for advancing and receding.

Method for testing marker repellency

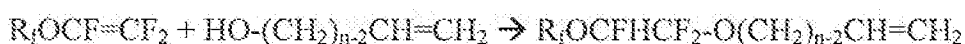
Example and Comparative Example samples were tested for their marker repellency using a black marker (black, Sanford Sharpie pen with Super Permanent Ink, available from Sanford Corp., Keysborough, Australia). A straight line was drawn on the coated sample and a repellency rating was assigned to the coated sample based on the appearance of the line: "No" meant that the coated sample was not repellent, i.e., the line was continuous; "Some" meant that the coated sample was somewhat repellent, i.e., the line was beaded-up with broken line; "Good" meant that the coated sample was repellent, but with some limited continuous lines; "Excellent" meant that the coated sample was repellent, with no continuous lines visible.

Method for testing coating durability

The durability of the coatings was determined by rubbing the sample surfaces (i.e., the coatings) using an abrasive Model 5900 TABER Reciprocating Abrasive apparatus with Crockmeter Standard Rubbing Cloth. The samples were rubbed at a speed of 75 cycles / minute, with an applied force of 13.6N. Samples were scratched for 50 cycles or 100 cycles and then their water and HD contact angles and marker repellency were determined to assess the durability of the coatings.

Preparation of fluorinated silanes

Fluorinated silanes (FS) according to the invention were made in a two-step process. First, fluoroalkenes, $R_f\text{-OCFHCF}_2\text{O}(\text{CH}_2)_{n-2}\text{-CH=CH}_2$, were prepared using procedures disclosed in the US Patent Publication, US2005/0113609, except using $\text{CH}_3\text{OCH}_2\text{CH}_2\text{OCH}_3$ as the solvent and with 5% excess of $R_f\text{-OCF=CF}_2$ according to the reaction



The reaction led to high yields of fluorinated alkenes (80~95%) which were subsequently isolated by distillation. Exemplary fluorinated alkenes produced as described above are listed below along with their boiling points (b.p.).

$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{OCH}_2\text{CH=CH}_2$,	b.p. 112-115°C;
$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_2\text{CH=CH}_2$,	b.p. 136-139°C;
$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_3\text{CH=CH}_2$,	b.p. 70-72.5°C / 39 mmHg;
$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_4\text{CH=CH}_2$,	b.p. 93-94°C/26 mmHg;
$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_5\text{CH=CH}_2$,	b.p. 95-97°C/5.3 mmHg;
$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_6\text{CH=CH}_2$,	b.p. 101-103°C/3.2 mmHg;
$\text{CF}_3\text{O}(\text{CF}_2)_3\text{OCHFCF}_2\text{O}(\text{CH}_2)_2\text{CH=CH}_2$,	b.p. 151-154°C;
$\text{CF}_3\text{O}(\text{CF}_2)_3\text{OCHFCF}_2\text{O}(\text{CH}_2)_4\text{CH=CH}_2$,	b.p. 92-94°C/26 mmHg;
$\text{C}_3\text{F}_7\text{OCF}(\text{CF}_3)\text{CF}_2\text{OCHFCF}_2\text{O}(\text{CH}_2)_2\text{CH=CH}_2$,	b.p. 75-78°C/16 mmHg

Then, the fluorosilanes, $R_f\text{-OCFHCF}_2\text{O}(\text{CH}_2)_n\text{-Si}(\text{OR})_3$ were made by hydrosilylation of $R_f\text{-OCFHCF}_2\text{O}(\text{CH}_2)_n\text{-CH=CH}_2$ with slightly excess of $\text{H-Si}(\text{OR})_3$ (1:1.1 mole ratio) at room temperature in the presence of $\text{Pt}(0)$ catalyst (40 ppm) under nitrogen according to the reaction



All of the $R\text{-OCFHC}_2\text{F}_2\text{O}(\text{CH}_2)_n\text{-CH=CH}_2$ prepared above (with the exception of $\text{C}_4\text{F}_9\text{-CH=CH}_2$) showed high reactivity to $\text{H-Si}(\text{OR})_3$ ($\text{R} = \text{Me, Et}$), and the hydrosilation reactions were completed in 10 minutes to 2 hours at room temperature, as monitored by FT-IR and ^1H NMR analyses. The formed silanes were isolated by distillation and the isolated yields from the distillation were $\geq 90\%$. The yield for the reaction of $\text{C}_4\text{F}_9\text{-CH=CH}_2$ was $< 5\%$. Exemplary fluorinated silanes produced as described above are listed below along with their boiling points (b.p.).

$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_3\text{Si}(\text{OEt})_3$ b.p. = $95\text{-}100^\circ\text{C}/5.9\text{ mmHg}$

$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_3\text{SiMe}(\text{OMe})_2$ b.p. = $96\text{-}100^\circ\text{C}/16\text{ mmHg}$

10 $\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_3\text{SiMe}_2(\text{OEt})$ b.p. = $95\text{-}101^\circ\text{C}/20\text{ mmHg}$

$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_4\text{Si}(\text{OMe})_3$ b.p. = $80\text{-}83^\circ\text{C}/1.7\text{ mmHg}$

$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_4\text{Si}(\text{OEt})_3$ b.p. = $97\text{-}100^\circ\text{C}/2.2\text{ mmHg}$

$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_5\text{Si}(\text{OMe})_3$ b.p. = $103\text{-}104^\circ\text{C}/4.2\text{ mmHg}$

$\text{C}_3\text{F}_7\text{OCHFCF}_2(\text{CH}_2)_6\text{Si}(\text{OMe})_3$ b.p. = $99\text{-}102^\circ\text{C}/1.8\text{ mmHg}$

15 $\text{C}_3\text{F}_7\text{OCHFCF}_2(\text{CH}_2)_{10}\text{Si}(\text{OMe})_3$ b.p. = $135\text{-}136^\circ\text{C}/2.1\text{ mmHg}$

$\text{C}_3\text{F}_7\text{OCHFCF}_2\text{O}(\text{CH}_2)_{11}\text{Si}(\text{OEt})_3$ b.p. = $148\text{-}152^\circ\text{C}/1.8\text{ mmHg}$

General method for preparing coating solutions and coating

Example and Comparative Example coating solutions were formulated by direct dilution of respective fluorinated silanes listed below in a desired solvent to 2 wt %. Then, 0.1 wt % of 0.1N nitric acid aqueous solution was added to the solution and the solutions were aged for at least 10 minutes before coating. Glass microscope slides (obtained from VWR International, Radnor, PA) were coated with coating solutions by dipping them into the solution. The resulting coatings were then cured at desired temperature for desired length of time before testing.

CFS-1, $\text{C}_8\text{F}_{17}(\text{CH}_2)_2\text{Si}(\text{OEt})_3$

CSF-2, $\text{C}_6\text{F}_{13}(\text{CH}_2)_2\text{Si}(\text{OMe})_3$

CSF-3, $\text{C}_4\text{F}_9(\text{CH}_2)_2\text{Si}(\text{OMe})_3$

30 CSF-4, $\text{C}_4\text{F}_9\text{SO}_2\text{NMeC}_3\text{H}_6\text{Si}(\text{OMe})_3$ (FC-4405)

CSF-5, ECC-1000, 0.1 wt % in HFE-7100

FS-1, $C_3F_7OCHF CF_2O(CH_2)_3Si(OMe)_3$

FS-2, $C_3F_7OCHF CF_2O(CH_2)_4Si(OEt)_3$

FS-3, $C_3F_7OCHF CF_2(CH_2)_6Si(OMe)_3$

FS-4, $C_3F_7OCHF CF_2(CH_2)_{10}Si(OMe)_3$

5 FS-5, $C_3F_7OCHF CF_2O(CH_2)_{11}Si(OEt)_3$

Examples 1- 7 (EX1-EX7) and Comparative Examples 1-5 (CE1-CE5)

EX1-7 and CE1-CE5 samples were prepared using the general method for preparing
 10 coating solutions and coating described above. The resulting coated glass slides were
 dried at room temperature for 2 minutes and then in an oven at 110 °C for 2 minutes.
 Then, the water and hexadecane contact angle measurements were done for EX1-EX7 and
 CE1-CE5 samples using the methods described above. The composition of the coating
 solutions (i.e., the fluorosilane and the solvent used) as well as the contact angle data are
 15 summarized below in Table 1. Note that multiple samples for a given Example (e.g.,
 EX3a, EX3b, etc.) denote that replicate samples were prepared and tested for a given
 Example.

Table 1

Example	Coating Composition (Fluorosilane, wt% in solvent)	Water Contact Angle (degrees)						Hexadecane Contact Angle (degrees)					
		Advancing		Receding		Static		Advancing		Receding		Static	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
CE1	CSF-1, 2% in IPA	110.7	110.7	67.7	67.7	106.6	106.6	61.3	59.9	25.6	25.6	50.6	51.2
CE2	CSF-2, 2% in IPA	110.8	110.8	70.2	69.7	107.6	107.2	65.0	65.0	27.9	27.9	60.8	60.8
CE3	CSF-3, 2% in IPA	103.6	103.1	72.6	73.0	97.6	97.6	68.7	67.8	44.6	44.6	58.4	58.4
CE4	CSF-4, 2% in IPA	116.3	116.3	79.8	79.8	107.1	107.1	79.5	79.5	53.4	53.4	63.2	63.2
CE5	CSF-5, 0.1% in HFE 7100	108.9	108.9	87.5	86.9	104.7	104.7	73.1	73.4	43.2	43.2	66.2	66.2
EX1	FS-1, 2% in IPA	89.6	89.6	73.6	73.6	81.6	81.6	51.2	51.2	40.6	40.6	47.1	47.1
EX2	FS-2, 2% in IPA	99.3	100.7	82.8	82.8	96.3	95.2	61.9	61.9	46.9	46.9	51.7	52.2

EX3a	FS-3, 2% in IPA	106.5	107.1	90.3	90.7	100.2	100.5	63.4	63.3	51.0	50.9	58.0	58.0
EX3b	FS-3, 2% in IPA	106.3	106.3	92.0	92.8	101.6	101.2	64.5	64.5	54.3	54.3	59.3	59.3
EX3c	FS-3, 2% in IPA	107.4	107.4	93.0	92.2	99.0	99.1	63.3	63.3	50.6	50.6	58.7	58.7
EX4a	FS-4, 2% in IPA	109.3	109.3	95.4	95.4	104.6	105.0	57.7	57.7	42.3	42.3	64.5	64.5
EX4b	FS-4, 2% in IPA	107.8	107.8	96.1	96.1	106.1	105.3	60.0	60.0	41.7	41.7	67.7	67.7
EX5a	FS-5, 2% in IPA	106.5	106.5	95.7	95.7	102.0	102.0	68.4	68.4	55.1	55.1	64.9	64.9
EX5b	FS-5, 2% in IPA	111.3	111.3	93.4	93.4	102.9	104.3	68.7	68.7	55.7	55.2	63.1	64.0
EX6a	FS-4, 2% in EtOH	109.2	109.2	95.2	95.2	103.5	103.5	74.4	74.4	49.3	49.3	61.0	61.0
EX6b	FS-4, 2% in EtOH	109.9	109.9	93.7	93.7	106.3	106.3	74.0	74.0	46.9	46.9	65.7	65.7
EX6c	FS-4, 2% in	109.5	109.5	96.3	96.3	102.8	102.8	75.1	75.1	48.5	48.5	64.8	64.8

[illegible]

The marker repellency of the EX1-EX7 and CE3-CE5 samples were determined as described above. The results are summarized below in Table 2.

Table 2

Example	Marker Repellency
CE3	No
CE4	Some
CE5	Good
EX1	No
EX2	Some
EX3	Excellent
EX4	Excellent
EX5	Excellent
EX6	Excellent
EX7	Excellent

5

The durability of the EX3-EX5 and CE3 samples were determined as described above after subjecting them to 50 or 100 cycles of abrasive rubbing. The results are summarized below in Table 3.

Table 3

Example	Abrasive cycles	Marker Repellency	Water Contact Angle (degrees)					
			Advancing		Receding		Static	
			Left	Right	Left	Right	Left	Right
CE3	50	No	79.3	79.3	41.2	41.2	77.8	77.8
EX3a	50		100.8	100.8	85.2	85.2	91.3	91.3
EX4a	50		106.6	106.6	95.1	95.1	100.9	100.9
EX4a	100		106.4	106.4	93.7	93.7	104.5	104.5
EX5a	50		106.0	106.0	91.2	91.2	98.6	98.6
EX5a	100		104.9	104.9	89.5	89.5	97.6	97.6
EX5b	50		106.9	106.9	90.9	90.9	96.6	96.6
EX5b	100		106.0	106.0	88.5	88.5	93.2	93.2

Examples 8-9 (EX8-EX9) and Comparative Example 6 (CE6)

5 EX8 samples were prepared in the same manner as EX3. EX9 samples were prepared in the same manner as EX3, except that the coated glass slides were dried at room temperature for 24 hours. CE6 was prepared in the same manner as CE5, except that the coated glass slides were dried at room temperature (RT) for 24 hours. EX8-EX9 and CE6 samples were tested for their water and HD contact angles. The data is summarized below in Table 4.

Table 4.

Example	Water Contact Angle (degrees)						Hexadecane Contact Angle (degrees)					
	Advancing		Receding		Static		Advancing		Receding		Static	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
EX8a	106.8	107.4	92.7	91.8	99.5	99.5	65.3	65.3	50.9	50.9	57.8	57.8
EX8b	106.1	106.1	92.0	92.0	97.3	97.3	64.6	64.6	49.6	49.6	57.1	57.1
EX9a	106.6	106.6	91.9	91.9	99.8	99.8	65.5	65.5	45.9	45.9	58.6	58.6
EX9b	107.9	107.9	93.2	93.0	98.0	98.0	66.4	66.4	44.2	44.2	61.8	61.8
CE6	108.5	109.6	72.6	72.4	102.5	102.5	79.8	79.7	55.1	56.0	66.1	66.1

Example 10 (EX10) and Comparative Example 7 (CE7)

EX10 and CE7 samples were prepared in the same manner as EX5 and CE5, respectively, except that the coating compositions did not include the addition of 0.1N nitric acid. EX10 and CE7 samples were tested for their water and HD contact angles. The data is summarized below in Table 5.

5

Table 5

Example	Water Contact Angle (degrees)				Hexadecane Contact Angle (degrees)			
	Advancing		Receding		Advancing		Receding	
	Left	Right	Left	Right	Left	Right	Left	Right
EX10a	111.3	111.3	93.4	93.4	102.9	104.3	68.7	64.0
EX10b	106.5	106.5	95.7	95.7	102.0	102.0	55.1	64.9
CE7	108.9	108.9	87.5	86.9	104.7	104.7	43.2	66.2

Examples 11-13 (EX10-EX13)

EX11-EX13 samples were prepared in the same manner as EX5, except that the concentration of the fluorosilane in the coating compositions was 1 wt%, 0.5 wt%, and 0.25 wt%, respectively. EX11-EX13 samples were tested for their water and HD contact angles. The data is summarized below in Table 6.

5

Table 6	
Sample	Water Contact Angle (°)
EX11	110
EX12	105
EX13	100

Table 6

Example	Water Contact Angle (degrees)						Hexadecane Contact Angle (degrees)					
	Advancing		Receding		Static		Advancing		Receding		Static	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
EX11a	107.9	107.9	91.0	91.0	99.7	99.7	66.3	66.3	41.2	41.2	62.4	62.4
EX11b	107.0	107.0	90.2	89.7	98.2	98.2	66.0	66.0	41.8	42.1	62.0	62.0
EX12a	101.3	101.3	89.8	90.7	96.4	96.6	67.4	67.4	39.8	40.2	61.3	61.3
EX12b	101.4	101.4	90.0	89.8	95.8	95.3	68.5	68.5	40.5	40.5	61.3	61.3
EX13a	91.7	91.7	78.9	78.9	80.3	81.7	62.6	62.6	33.9	33.9	51.8	51.8
EX13b	91.2	91.2	76.7	76.7	80.0	80.0	64.1	64.3	34.7	34.7	53.5	53.5

Examples 14-15 (EX14-EX15) and Comparative Examples 8-9 (CE8-CE9)

EX14-EX15 and CE8-CE9 samples were prepared in the same manner as EX2, EX3, CE2, and CE4, respectively, except that the coating compositions further included TEOS. The relative amount of the TEOS to the corresponding fluorosilanes was 30 wt% TEOS to 70 wt% fluorosilane. TEOS and fluorosilane, collectively, were diluted to 2 wt% in IPA. EX14-EX15 and CE8-CE9 samples were tested for their water and HD contact angles. The data is summarized below in Table 7.

5

Table 7

Example	Water Contact Angle (degrees)				Hexadecane Contact Angle (degrees)			
	Advancing		Receding		Advancing		Receding	
	Left	Right	Left	Right	Left	Right	Left	Right
CE8	108.7	108.7	92.0	92.0	103.6	103.6	70.7	70.5
CE9	119.8	119.8	63.5	63.5	103.0	102.2	108.4	108.4
EX14	109.8	109.8	84.1	84.1	98.4	98.4	69.1	68.3
EX15	106.5	106.5	93.4	93.4	100.3	100.3	68.9	68.9
							51.7	51.7
							58.7	58.7
							63.8	63.8
							62.0	61.4
							58.6	58.6
							63.5	63.5

This disclosure provides the following illustrative embodiments:

1. A fluoroalkylsilane of the formula:



R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain $-O-$, $-S-$ or $-NR_f^1$ - heteroatoms, where R_f^1 is a perfluoroalkyl;

X is a hydrolysable group;

R is a C_1 - C_4 alkyl group;

q is at least 3; and

x is 1 to 3.

2. The fluoroalkylsilane of embodiment 1 wherein R_f is a C_1 - C_6 perfluoroalkyl group.

3. The fluoroalkylsilane of any of the previous embodiments wherein X is selected from alkoxy, acetoxy and halide.

4. The fluoroalkylsilane of any of the previous embodiments wherein q is at least 6.

5. The fluoroalkylsilane of any of embodiments 1, 3 or 4 wherein R_f is of the formula $C_nF_{2n+1}-(O-C_mF_{2m})_p-$, where n is at least 1, m is at least 2, and p may be zero or a number from 1 to 10.

6. The fluoroalkylsilane of embodiment 5 wherein each of subscripts n and m are 3 to 6.

7. The fluoroalkylsilane of any of embodiments 1, 3 or 4 wherein R_f is of the formula $C_nF_{2n+1}N(C_{2o}F_{2o+1})-C_mF_{2m}-$, where n is at least 1, o is at least 1 and m is at least 2.

8. The fluoroalkylsilane of embodiment 7 wherein each of subscripts n , and m are 3 to 6.

9. The fluoroalkylsilane of any of embodiments 1, 3 or 4 where R_1 is selected from CF_3 , C_2F_5 , C_3F_7 and $CF_3O(CF_2)_3$; q is 6 and greater and X is selected from Cl , OCH_3 , OCH_2CH_3 , $OCH_2CH_2CH_3$ and $OCH(CH_3)_2$.
- 5 10. A coating composition comprising the fluoroalkyl silane of any of embodiments 1-9, a solvent and optional acid catalyst and optional inorganic oxide particulate filler.
11. The coating composition of embodiment 10, wherein the particulate filler is silica.
- 10 12. The coating composition of embodiment 11 wherein the silica is nanoparticle silica.
13. The coating composition of any of embodiments 11 or 12 wherein the silica is surface modified.
- 15 14. The coating composition of any of embodiments 11-13 further comprising one or more silane crosslinkers of the formula:

$$Si(X^1)_zR^{2*}_{4-z}$$
 wherein each X^1 is independently hydroxyl, a hydrolyzable group, or a combination thereof; each R^{2*} is independently a C_1 - C_4 alkyl group; z is an integer of one to four.
- 20 15. The coating composition of embodiment 14 wherein z is four.
- 25 16. The coating composition of embodiment 15 comprising a mixture of silane crosslinkers where z is 3 and 4.
17. The coating composition of embodiment 15 comprising 1 to 20 weight percent of silane crosslinkers.

18. The coating composition of and of embodiments 11-16 comprising 1 to 20 wt.% of silica.
19. The coating composition of embodiment 11 comprising:
 - a) 0.25 to 10 wt.% fluoroalkyl silane
 - b) 0 to 20 wt.% silica
 - c) 0 to 20 wt.% a silane crosslinker,
 - d) 0 to 10 wt.% of an acid catalyst;
 in an organic solvent.
20. The coating composition of any of the previous embodiments further comprising 0.01 to about 10 weight percent of an acid catalyst.
21. The coating composition of embodiments 19 or 20 comprising 0.5 to 5 wt% fluoroalkylsilane.
22. The coating composition of any of embodiments 19-21 comprising 1 to 10 wt% nanoparticle silica.
23. The coating composition of any of embodiments 19-21 comprising 1 to 10 wt% silane crosslinker.
24. A method of making the fluoroalkylsilane of the coating composition of any of the previous embodiments comprising the steps of hydrosilation of a fluorinated compound of the formula:

$$R_f-O-CH_2CF_2-O-(CH_2)_{q-2}CH=CH_2$$
 wherein R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain -O-, -S- or -NR¹- heteroatoms, where R_f^1 is a perfluoroalkyl;
 with a hydrosilane of the formula:

$$H-Si(X)_xR_{3-x}$$
 wherein X is a hydrolysable group;

R is a C₁-C₄ alkyl group; and

x is 1 to 3;

in the presence of a hydrosilation catalyst.

25. The method of embodiment 24 wherein the fluorinated compound is prepared by reaction of a compound of the formula:

$R_f-O-CF=CF_2$ with a compound of the formula:

$H-O-(CH_2)_q-CH=CH_2$, in the presence of a base catalyst,

where n and R_f are as previously defined.

R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain -O-, -S- or -NR_f¹- heteroatoms, where R_f¹ is a perfluoroalkyl and q is at least 3.

26. A coated article comprising a substrate and the cured coating of any of embodiments 1-23 on a surface thereof.

27. The coated article of embodiment 26 having a receding contact angle of at least 80°, at least 90°.

28. The coated article of embodiment 27 wherein the coating is of the general formula:

$[R_f^2SiO_{3/2}]_a[SiO_{4/2}]_b[RSiO_{3/2}]_c$, where

R_f² is R_f-O-CH₂CF₂-O-(CH₂)_q- is the unit is derived from the fluoroalkylsilane of Claim 1 where subscript "x" is 3,

[SiO_{4/2}] are units derived from the crosslinking silanes having four hydrolysable groups; [RSiO_{3/2}] are units derived from the crosslinking silanes having three hydrolysable groups, and subscripts a, b and c are numbers corresponding to the weight percents of each unit.

29. The coated article of any of embodiments 26-28 wherein the substrate is siliceous.

What is claimed is:

1. A fluoroalkylsilane of the formula:

$$R_f-O-CHF_2CF_2-O-(CH_2)_q-Si(X)_xR_{3-x}$$
, wherein
 R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain --O-, -S- or --NR¹- heteroatoms, where R_f^1 is a perfluoroalkyl;
 X is a hydrolysable group;
 R is a C₁-C₄ alkyl group;
 q is at least 3; and
 x is 1 to 3.
2. The fluoroalkylsilane of claim 1 wherein R_f is a C₁-C₆ perfluoroalkyl group.
3. The fluoroalkylsilane of claim 1 wherein X is selected from alkoxy, acetoxy and halide.
4. The fluoroalkylsilane of claim 1 wherein q is at least 6.
5. The fluoroalkylsilane of claim 1 wherein R_f is of the formula $C_nF_{2n+1}-(O-C_mF_{2m})_p-$, where n is at least 1, m is at least 2, and p may be zero or a number from 1 to 10.
6. The fluoroalkylsilane of claim 5 wherein each of subscripts n and m are 3 to 6.
7. The fluoroalkylsilane of claim 1 wherein R_f is of the formula $C_nF_{2n+1}N(C_{2o}F_{2o+1})_oC_mF_{2m+1}$, where n is at least 1, o is at least 1 and m is at least 2.
8. The fluoroalkylsilane of claim 7 wherein each of subscripts n , and m are 3 to 6.
9. The fluoroalkylsilane is of claim 1 where R_f is selected from CF₃, C₂F₅, C₃F₇ and CF₃O(CF₂)₃; q is 6 and greater and X is selected from Cl, OCH₃, OCH₂CH₃, OCH₂CH₂CH₃ and OCH(CH₃)₂.

10. A coating composition comprising the fluoroalkyl silane of any of claims 1-9, a solvent and optional acid catalyst and optional inorganic oxide particulate filler.
- 5 11. The coating composition of claim 11, further comprising silica.
12. The coating composition of claim 11 wherein the silica is nanoparticle silica.
13. The coating composition of claim 11 wherein the silica is surface modified.
- 10 14. The coating composition of claim 11 further comprising one or more silane crosslinkers of the formula:

$$\text{Si}(\text{X}^1)_z\text{R}^2_{4-z}$$
 wherein each X^1 is independently hydroxyl, a hydrolyzable group, or a combination thereof; each R^2 is independently a C_1 - C_4 alkyl group; z is an integer of one to four.
- 15 15. The coating composition of claim 14 wherein z is four.
16. The coating composition of claim 15 comprising a mixture of silane crosslinkers where z is 3 and 4.
- 20 17. The coating composition of claim 15 comprising 1 to 20 weight percent of silane crosslinkers.
- 25 18. The coating composition of claim 11 comprising 1 to 20 wt.% of silica.
- 30 19. The coating composition of claim 11 comprising:
 - a) 0.25 to 10 wt.% fluoroalkyl silane
 - b) 0 to 20 wt.% silica
 - c) 0 to 20 wt.% a silane crosslinker,
 - d) 0 to 10 wt.% of an acid catalyst;

in an organic solvent.

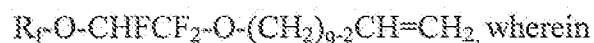
20. The coating composition of claim 11 further comprising 0.01 to about 10 weight percent of an acid catalyst.

21. The coating composition of claim 11 comprising 0.5 to 5 wt% fluoroalkylsilane.

22. The coating composition of claim 11 comprising 1 to 10 wt% nanoparticle silica.

23. The coating composition of claim 11 comprising 1 to 10 wt% silane crosslinker.

24. A method of making the fluoroalkylsilane of claim 1 comprising the steps of hydrosilation of a fluorinated compound of the formula:



R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain -O-, -S- or -NR¹- heteroatoms, where R_f^1 is a perfluoroalkyl; with a hydrosilane of the formula:



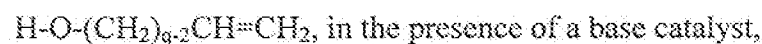
X is a hydrolysable group;

R is a C₁-C₄ alkyl group; and

x is 1 to 3;

in the presence of a hydrosilation catalyst.

25. The method of claim 24 wherein the fluorinated compound is prepared by reaction of a compound of the formula:



where n and R_f are as previously defined.

R_f is a perfluoroalkyl group, optionally substituted by one or more in-chain -O-, -S- or -NR¹- heteroatoms, where R_f^1 is a perfluoroalkyl and q is at least 3.

26. A coated article comprising a substrate and the cured coating of claim 11 on a surface thereof.
27. The coated article of claim 26 having a receding contact angle of at least 80°, at least 90°.
28. The coated article of claim 27 wherein the coating is of the general formula: $[R_f^2SiO_{3/2}]_a[SiO_{4/2}]_b[RSiO_{3/2}]_c$, where R_f^2 is $R_f-O-CH_2CF_2-O-(CH_2)_q-$ is the unit is derived from the fluoroalkylsilane of Claim 1 where subscript "x" is 3, $[SiO_{4/2}]$ are units derived from the crosslinking silanes having four hydrolysable groups; $[RSiO_{3/2}]$ are units derived from the crosslinking silanes having three hydrolysable groups, and subscripts a, b and c are numbers corresponding to the weight percents of each unit.
29. The coated article of claim 27 wherein the substrate is siliceous.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/056865

A. CLASSIFICATION OF SUBJECT MATTER
INV. C07F7/18 C08G77/24
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C07F C08G

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, CHEM ABS Data, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP H01 226844 A (TOKUYAMA SODA KK) 11 September 1989 (1989-09-11) pages 19-24 -----	1-29
A	US 3 484 470 A (PITTMAN ALLEN G ET AL) 16 December 1969 (1969-12-16) claim 1 -----	1-29
A	WO 2010/144352 A2 (3M INNOVATIVE PROPERTIES CO [US]; FAN WAYNE W [US]; ARCO MANUEL [US];) 16 December 2010 (2010-12-16) claim 1 -----	1-29



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/056865

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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