COMPOSITIONS AND METHODS FOR GEL ELECTROLYTE BATTERIES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to and benefit of U.S. provisional application serial no. 63/572,116 filed March 29, 2024, the entire contents of which are incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] Metal Ion Batteries (MIBs) consist of an anode and a cathode that are kept apart from each other via a semipermeable membrane known as a separator. The battery is completed by filling it with an electrolyte solution containing metal ions. During discharge of the battery, the metal ions move from the anode (negative electrode) through the electrolyte solution to the cathode (positive electrode). When the battery is being charged the lithium ions move in reverse, from the cathode to the anode of the battery.

[0003] Lithium Ion Batteries (LIBs) are a ubiquitous type of metal ion batteries. Typically, the anode is lithium intercalated graphite and the cathode is a variety of materials including lithium iron phosphate (LFP), nickel manganese cobalt (NMC) and many others materials with the ability to host lithium ions. Typical liquid electrolytes are comprised of carbonates such as propylene and ethylene carbonate, which dissolve the lithium hexafluorophosphate salt.

[0004] While the performance of LIBs is extraordinary, there are areas where improvement is needed. There is also a need for improvement for MIBs generally. For example, when the electrolyte is added to the battery, the time it takes to completely wet the complex structures of the electrodes and separator dictates how much time it takes to manufacture batteries. There currently exists a need for faster wetting times to reduce time spent in manufacturing MIBs. Furthermore, it

is desirable to have the greatest initial capacity for a battery and for that capacity to stay as high as possible during cycling. Thus, there currently exists a need to improve the initial capacity (and to maintain capacity) of MIBs. Moreover, there are occasionally catastrophic events caused by dendrite formation in some MIBs that cause failure of the battery and, in some cases, cause fires that are extremely challenging to extinguish. Thus, there exists a need to mitigate and/or eliminate these catastrophic events for improved safety and for improved economics (e.g., longer battery lifetime).

[0005] The present disclosure addresses these and other needs.

SUMMARY OF THE INVENTION

[0006] According to some aspects, the present disclosure provides a new class of additives for lithium-ion batteries that has an unusual, unexpected, and highly desirable suite of properties. In some embodiments, the additives disclosed herein comprise N-isopropylacrylamide oligomers attached to a terminal group with the formula $C_6F_{13}CH_2CH_2S$-(N-isopropylacrylamide)$_n$-H, wherein n is an average value representing a distribution of different chain lengths. In some embodiments, n=4. In some embodiments, n is greater than 4. In some embodiments, n is anywhere from 4 to 30. In some embodiments, the additives disclosed herein can be formulated as co-polymers with other acrylamide subunits while maintaining or enhancing the improved properties disclosed herein (e.g., mPEG acrylate derivatives copolymerized with NIPAM derivatives).

[0007] In some embodiments, the additives disclosed herein have the following unexpected and highly desirable suite of properties:

[0008] *Gelation:* In some embodiments, the additives disclosed herein are highly soluble in carbonate and ether-based electrolyte and form solutions at concentrations between (0.1% to 50%

by wt.). In some embodiments, these materials form gels or viscous liquids in the electrolytes (*See, e.g.*, Example 3, Figure 1), which are highly desirable because they then limit the vapor pressure of the flammable electrolyte.

[0009] *Elimination of Capacity Fade:* In some embodiments, the additives disclosed herein when added to the electrolyte is effective to provide the batteries the ability to cycle with essentially no loss in capacity (*See, e.g.*, Example 4, Figure 2).

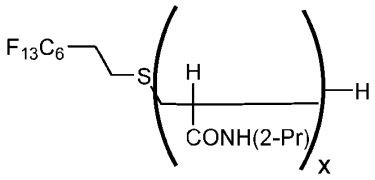
[0010] *Dendrite Suppression:* In some embodiments, the additives disclosed herein, when used in a battery, are effective to eliminate the formation of dendrites thereby reducing the risk associated with fires from the batteries. As disclosed herein, this effect is shown in the imaging of the battery's electrolyte and separator with and without the additives after cycling (*See, e.g.*, Figure 3a and Figure 3b in Example 5). In some embodiments, the batteries with the additives as disclosed herein also prevent failure during overcharge (*See, e.g.*, Figure 3c in Example 5).

[0011] *Fire resistance:* In some embodiments, the additives disclosed herein are effective to render the electrolyte solution fire resistant. As disclosed herein, this effect is shown in Example 7, Figure 5. In some embodiments, the additives disclosed herein are effective to prevent a flammable electrolyte from igniting. In some embodiments, the additives disclosed herein are effective to self-extinguish a flammable electrolyte.

[0012] According to some aspects, the present disclosure provides a fluorocarbon surfactant according to Formula I: $R_f–E_n–S–[\text{N-isopropylacrylamide}]_x[M_1]_yH$ (I), wherein R_f is a straight or branched chain perfluoroalkyl of 4 to 18 carbon atoms, perfluoroalkyloxyalkylene of 5 to 19 carbon atoms, or mixtures thereof; E_n is a straight or branched chain alkylene of 1 to 12 carbon atoms, —CON(R') —E'—, —SO_2N(R') —E'—, —E"—CON(R') —E'—, —E"—S—E'—, —E"—N(R') —E'—; or —E"—SO_2N(R') —E'-, where R' is hydrogen or alkyl of 1 to 6 carbon

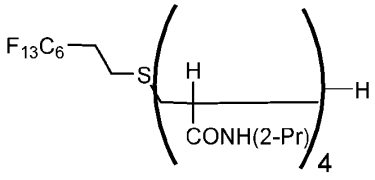
atoms, E' is alkylene of 2 to 8 carbon atoms and E" is alkylene of 1 to 4 carbon atoms; [M_1] represents a hydrophilic monomer unit derived from a hydrophilic monomer of the type M_1; wherein M_1 is optionally more than one type of monomer; wherein the sum of x and y is between 1 and about 500; x/(x+y) is between 1 and 0.05; and n is 0 or 1.

[0013] In some embodiments, a fluorocarbon surfactant disclosed herein has the structure:



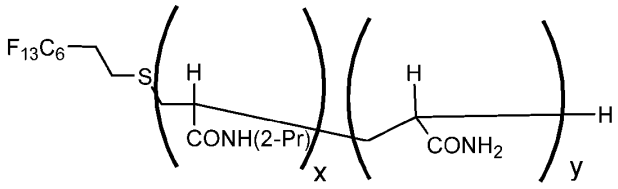
[0014] wherein x is from 1 to 40.

[0015] In some embodiments, a fluorocarbon surfactant disclosed herein has the structure:



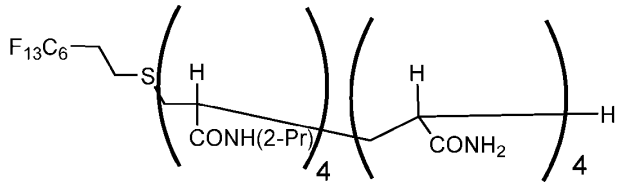
[0016]

[0017] In some embodiments, a fluorocarbon surfactant disclosed herein has the structure:

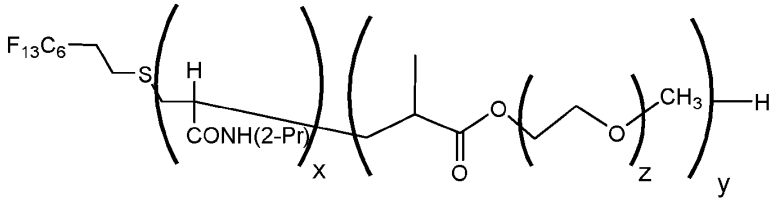


[0018] wherein x is from 1 to 40 and y is from 1 to 40.

[0019] In some embodiments, a fluorocarbon surfactant disclosed herein has the structure:



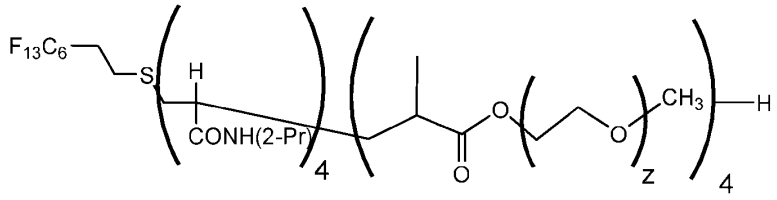
[0020] The fluorocarbon surfactant of claim 1, having the structure:



[0021]

[0022] wherein x is from 1 to 40, y is from 1 to 40, and z is from 1 to 5.

[0023] In some embodiments, a fluorocarbon surfactant disclosed herein has the structure:



[0024] wherein z is from 4 to 5.

[0025] According to some aspects, the present disclosure provides an ion battery electrolyte comprising an electrolyte salt, a solvent, and at least one fluorocarbon surfactant according to any embodiment disclosed herein. In some embodiments, the electrolyte salt is an electrolyte lithium salt. In some embodiments, the solvent comprises one or more of dimethyl carbonate, diethyl carbonate, methyl ethyl carbonate.

[0026] According to some aspects, the present disclosure provides an ion battery comprising: a housing comprising an electric core, and an electrolyte disposed in said housing,

wherein the electric core is in contact with the electrolyte and the electrolyte comprises at least one fluorocarbon surfactant according to any one of embodiments disclosed herein. In some embodiments, the at least one fluorocarbon surfactant is according to Formula I and comprises about 0.1% to about 60% by weight of the electrolyte. In some embodiments, the at least one fluorocarbon surfactant according to Formula I comprises about 2% to about 10% by weight of the electrolyte. In some embodiments, the at least one fluorocarbon surfactant according to Formula I comprises about 33% to about 50% by weight of the electrolyte. In some embodiments, the ion battery is a lithium-ion battery comprising a lithium salt. In some embodiments, the lithium salt is selected from $LiClO_4$, $LiPF_6$, $LiBF_4$, $LiCF_3SO_3$, $LiN(CF_3SO_2)_2$, or combinations thereof. In some embodiments, the electrolyte comprises a solvent selected from dimethyl carbonate, diethyl carbonate, methyl ethyl carbonate, and combinations thereof.

[0027] According to some aspects, the present disclosure provides, a method for improving performance of a metal ion battery comprising the step of contacting the metal ion battery with any ion battery electrolyte disclosed herein. In some embodiments, the improved performance includes improved charge capacity, fade during charge, discharge cycling, and reduced flammability of the metal ion battery relative to a metal ion battery without fluorocarbon surfactant. In some embodiments, the improved performance includes reduced dendrite formation during charge and discharge cycling of the metal ion battery relative to a metal ion battery without fluorocarbon surfactant. In some embodiments, the improved performance includes an increased lifetime of the metal ion battery relative to a metal ion battery without fluorocarbon surfactant. In some embodiments, the metal ion battery is a lithium-ion battery.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

[0029] The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of specific embodiments presented herein.

[0030] **Figure 1** shows gelation properties of additives at high mass loadings. In the case of KF-1-157-1 (n =14 NIPAM derivative), (a) viscous liquid electrolytes are formed with 10wt% mass loading, (b) homogeneous gel electrolytes are formed with 33wt% mass loadings, and (c) gel electrolytes are also formed with higher loadings (50wt% shown) though homogeneity was not achieved with simple stirring.

[0031] **Figure 2** shows cycling results at mass loadings of 0.5wt%, 1wt%, 2.5wt%, 5wt%, and 10wt% for additives (a) KF-1-156-1 (n = 4 NIPAM derivative) and (b) KF-1-157-1 (n =14 NIPAM derivative).

[0032] **Figure 3** shows the presence of dendrites in (a) recovered battery electrolytes and (b) recovered battery separators after long-term cycling studies (1000 cycles). Batteries were opened under argon atmosphere and disassembled to assess dendrite formation. Both KF-1-156-1 (n = 4 NIPAM derivative) and KF-1-157-1 (n =14 NIPAM derivative) effectively suppress dendrite formation (no dendrites in electrolyte for KF-1-156-1, substantially less dendrites for KF-1-157-1 relative to control cell). Similar observations are found when assessing the separator material. Figure 3(c) shows the results of overcharge tests, wherein cycling results were tested at

mass loadings of 2.5wt% for additives KF-1-156-1 (n = 4 NIPAM derivative) and KF-1-157-1 (n =14 NIPAM derivative) during overcharge testing to a voltage of 4.6 V.

[0033] **Figure 4** shows cycling results at mass loadings of 2wt%, 5wt%, and 10wt% for $C_6F_3CH_2CH_2$-$(NIPAM)_4(MPEG)_4$-H (identifier: KF-2-12-1).

[0034] **Figure 5** shows the results of fire resistance flame test on electrolyte with additives as disclosed herein (b) and (c) compared to electrolyte without additive (a). t=0 is the time of contact of the electrolyte to a flame.

DETAILED DESCRIPTION

NIPAM derivative compositions

[0035] According to some aspects, the present disclosure provides perfluoroalkyl group terminated oligomers derived from perfluoroalkyl mercaptans and N-isopropylacrylamide monomers that are polymerized through free radical reactions, and their use to improve MIB performance.

[0036] According to certain embodiments, the perfluoroalkyl group terminated oligomers (Rf-oligomer) are represented by the following formula I:

$$R_f–E_n–S–[\text{N-isopropylacrylamide}]_x[M_1]_yH \quad (I)$$

wherein R_f is a straight or branched chain perfluoroalkyl of 4 to 18 carbon atoms, perfluoroalkyloxyalkylene of 5 to 19 carbon atoms, or mixtures thereof; E_n is a straight or branched chain alkylene of 1 to 12 carbon atoms, —CON(R')—E'—, —SO_2N(R')—E'—, —E"—CON(R')—E'—, —E"—S—E'—, —E"—N(R')—E'—; or —E"—SO_2N(R')—E'-, where R' is hydrogen or alkyl of 1 to 6 carbon atoms, E' is alkylene of 2 to 8 carbon atoms and E" is alkylene of 1 to 4 carbon atoms; and $[M_1]$ represents a hydrophilic monomer unit derived from a hydrophilic

monomer of the type M_1; wherein M_1 is optionally more than one type of monomer; wherein the sum of x and y is between 1 and about 500; x/(x+y) is between 1 and 0.05; and n is 0 or 1.

[0037] In some embodiments, the formula above does not depict the actual sequence of the oligomer units, since the units can be randomly distributed.

[0038] In some embodiments, the oligomers disclosed herein are synthesized by polymerizing a N-isopropylacrylamide monomer, with or without a hydrophilic monomer or monomers of the type M_1 as disclosed herein, in the presence of an R_f -mercaptan of formula II

$$R_f\text{-}E_n\text{-}SH \quad (II)$$

[0039] wherein R_f and E_n are as disclosed herein.

[0040] R_f mercaptans of formula II are described *inter alia* in U.S. Pat. Nos. 2,894,991; 2,961,470; 2,965,677; 3,088,849; 3,172,910; 3,554,663; 3,655,732; 3,686,283; 3,883,596; 3,886,201 and 3,935,277; and Australian Application No. 36868; filed Apr. 24, 1968, each of which are incorporated by reference as if recited in full herein.

[0041] Suitable R_f mercaptans can, alternatively, be easily prepared by reacting an R_f acid halide, e.g., $R_f\ SO_2\ Cl$ or $R_f\ COCl$ with an amino mercaptan, e.g., H-N(R')-E'-SH, in an inert solvent.

[0042] In some embodiments, hydrophilic monomers of the type M_1 which contain at least one hydrophilic group are known and are commercially available, such as acrylic and methacrylic acid and salts thereof as well as hydrophilic groups containing derivatives such as their hydroxyalkyl esters, e.g., 2-hydroxyethyl, 3-hydroxypropyl, 2-hydroxypropyl or 2,3-hydroxypropyl esters; also ethoxylated and polyethoxylated hydroxyalkyl esters, such as esters of alcohols of the formula

$$HO\text{-}C_m\ H_{2m}\text{-}O\text{-}(CH_2\text{-}CH_2\text{-}O)_n\text{-}R_1$$

wherein R_1 represents hydrogen or methyl, m represents 2 to 5 and n represents 1 to 20 or esters of analogous alcohols, wherein a part of the ethylene oxide units is replaced by propylene oxide units. Further suitable esters are dialkylaminoalkyl acrylates and methacrylates, such as the 2-(dimethylamino)-ethyl-, 2-(diethylamino)-ethyl- and 3-(dimethylamino) -2-hydroxypropyl esters. Another class of hydrophilic monomers are acrylamide and methacrylamide as well as amides substituted by lower hydroxyalkyl, lower oxaalkyl- or lower dialkylaminoalkyl groups such as N-(hydroxymethyl)-acrylamide and -methacrylamide, N-(3-hydroxypropyl)-acrylamide, N-(2-hydroxyethyl)-methacrylamide, N-(1,1-dimethyl-3-oxabutyl)-acrylamide and N-[1,1-dimethyl-2-(hydroxymethyl)-3-oxabutyl)]-acrylamide; further hydrophilic monomers of interest are hydrazine derivatives, such as trialkylamine methacrylimide, e.g., trimethylamine-methacrylimide and dimethyl-(2-hydroxypropyl)amine methacrylimide and the corresponding derivatives of acrylic acid; mono-olefinic sulfonic acids and their salts, such as sodium ethylene sulfonate, sodium styrene sulfonate and 2-acrylamido-2-methylpropanesulfonic acid; N-[2-(dimethylamino)-ethyl]-acrylamide and -methacrylamide, N-[3-(dimethylamino)-2-hydroxypropyl]-methacrylamide, or mono-olefinic derivatives of heterocyclic nitrogen-containing monomers, such as N-vinyl-pyrrole, N-vinyl-succinimide, 1-vinyl-2-pyrrolidone, 1-vinyl-imidazole, 1-vinyl-indole, 2-vinyl-imidazole, 4(5)-vinyl-imidazole, 2-vinyl-1-methyl-imidazole, 5-vinyl-pyrazoline, 3-methyl-5-isopropenyl, 5-methylene-hydantoin, 3-vinyl-2-oxazolidone, 3-methacrylyl-2-oxazolidone, 3-methacrylyl-5-me-2-oxazolidone, 3-vinyl-5-methyl-2-oxazolidone, 2- and 4-vinyl-pyridine, 5-vinyl-2-methyl-pyridine, 2-vinyl-pyridine-1-oxide, 3-isopropenyl-pyridine, 2- and 4-vinyl-piperidine, 2- and 4-vinyl-quinoline, 2, 4-dimethyl-6-vinyl-s-triazine, 4-acrylyl-morpholine as well as the quaternized derivatives of the above pyridines.

[0043] In some embodiments, the above listed hydrophilic monomers of type M_1 can be used alone or in combination with each other.

[0044] In some embodiments, hydrophilic monomers of type M_1 which require a comonomer for polymerization are maleates, fumarates and vinylethers; the following monomer combinations are, for instance, useful: di(hydroxyalkyl) maleates, such as di(2-hydroxyethyl) maleate, and ethoxylated hydroxyalkyl maleates, hydroxyalkyl monomaleates, such as 2-hydroxyethyl monomaleate and hydroxylated hydroxyalkyl monomaleate with vinyl ethers, vinyl esters, styrene or generally any monomer which will easily copolymerize with maleates or fumarates; hydroxyalkyl vinyl ethers, such as 2-hydroxyethyl vinyl ether, 4-hydroxybutyl vinyl ether, with maleates, fumarates, or generally all monomers which will easily copolymerize with vinyl ethers.

[0045] In some embodiments, the hydrophilic monomers of type M_1 are acrylic acid, methacrylic acid, acrylamide, diacetone acrylamide, acrylamidopropane sulfonic acid and salts thereof, and hydroxyethyl methacrylate.

[0046] In some embodiments, the mercaptans act as so-called chain transfer agents in free-radical polymerization and copolymerization reaction. The previously listed hydrophilic monomers of type M_1 will either homopolymerize and/or copolymerize with N-isopropylacrylamide (NIPAM) monomer in the presence of a free-radical initiator and therefore readily react with R_f -mercaptans of formula II forming the instant R_f-oligomers of formula I in high yield.

[0047] In some embodiments, the polymerization reaction is performed in an essentially water free reaction medium, preferably in a lower alcohol such as methanol or isopropanol, or acetone or a lower cellosolve which dissolve the reactants and catalyst.

[0048] In some embodiments, the oligomerization temperature is maintained at a temperature between 20 degrees and 60 degrees C., but temperatures up to 100 degrees C. may be used. Optimum temperature may be readily determined for each oligomerization and will depend on the reaction, the relative reactivity of the monomers and the specific feed-radical initiator used. In some embodiments, in order to facilitate the free-radical propagation necessary for an effective catalyst reaction an oxygen-free atmosphere is desirable, and the oligomerizations are carried out under nitrogen.

[0049] In some embodiments, the catalyst employed must be a free-radical initiator, such as the peroxides, persulfates or azo compounds. In some embodiments, organic peroxides and hydroperoxides, hydrogen peroxides, azo catalysts and water soluble persulfates are used. Specific examples include ammonium persulfate, lauroyl peroxide, tertbutyl peroxide and particularly the azo catalysts 2,2'-azobis(isobutyronitrile); 2,2'-azobis(2,4-dimethylvaleronitrile); 2-tert-butylazo-2-cyanopropane; 1-tert-butylazo-1-cyanocyclohexane; and 2,2'-azobis(2,4-dimethyl-4-methoxyvaleronitrile).

[0050] In some embodiments, catalytic amounts of initiator are used, that is between 0.01 and 0.5% by weight of monomers depending on the particular initiator and monomer system. In some embodiments, azo catalyst from 0.01 to 0.2% by weight of azocatalyst per weight of monomers are used.

[0051] In some embodiments, R_f -oligomers of formula I

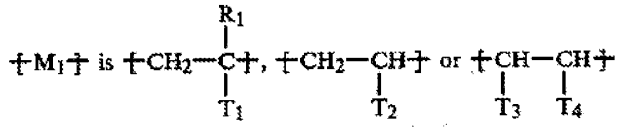
$$R_f–E_n–S–[\text{N-isopropylacrylamide}]_x[M_1]_yH \qquad (I)$$

are prepared from a wide variety of R_f -mercaptans of formula II

$$R_f\text{-}E_n\text{-}SH \qquad (II)$$

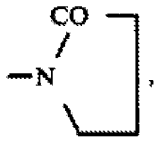
and a vast number of commercially available monomers of type M_1 and M_2 as defined herein.

[0052] In some embodiments, R_f is a perfluoroalkyl group with 6 to 14 carbon atoms, E is alkylene, preferably ethylene,

[0053] 

[0054] wherein T_1 is --COOMe; --$CONH_2$; --$CONHR_2$; --CONH R_3 ; --CONH--E_1 --NR_2 R_3 ; --CONH--E_1 --NR_2 R_3 R_4 X; --$CONHCH_2$ OH; --$CONHCH_2$ OR_2 ; --$CONHE_2$ OH; --$CO(OE_1)_n$ OR_1 ; --$COOCH_2$ $CHOHCH_2$ OH; --CONH--E_2 --SO_3 Me; --$CON(E_1$ $OH)_2$;

[0055] T_2 is --OH; --OE_2 OR_1 ; --$(OE_1)_n$ OR_1 ; --SO_3 Me; --C_6 H_4 SO_3 Me;



pyridinium halide, --$NHCOR_1$, --NH_2 T_3 & T_4 are independently --COOMe; --$CONH_2$; --$CO(OE_1)_n$ OR_1 ; --CONH--E_1 --OH; --$CON(E_1$ --$OH)_2$

[0056] R_1 is hydrogen or methyl

[0057] R_2, R_3, R_4 are independently alkyl with 1 to 6 carbons

[0058] E_1 is alkylene with 2 or 3 carbons

[0059] E_2 is alkylene with 2 to 6 carbons

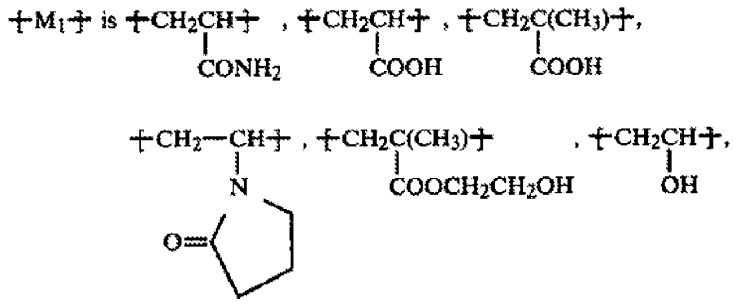
[0060] Me is hydrogen or alkali metal

[0061] X is halide and

[0062] n is 1 to 20

[0063] In some embodiments, R_f -oligomers have the structure R_f —E—S—[N-isopropylacrylamide]$_x$[M_1]$_y$ H, wherein R_f is linear perfluoroalkyl with 6 to 12 carbon atoms

[0064] E is –CH_2 CH_2 –

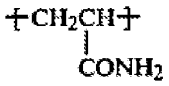


[0065]

[0066] x is 4 to 50

[0067] and y is 4 to 50.

[0068] In some embodiments, R_f -oligomers used as electrolyte additives have the above listed structure R_f—E—S—[N-isopropylacrylamide]$_x$[M_1]$_y$ H, wherein -M_1- is



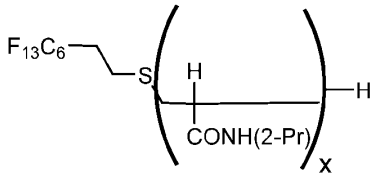
[0069] and y varies from 4 to 50.

[0070] According to some embodiments, electrolyte additives comprise one or more of the compounds according to Compound 1, Compound 2, Compound 3, Compound 4, Compound 5, Compound 6, Compound 7, Compound 8, Compound 9, Compound 10, Compound 11, or Compound 12 disclosed herein. According to some embodiments, electrolyte additives disclosed herein comprise one or more commercial products, such as DX1080 or DX1090 (Dynax). In some embodiments, the commercial products, such as DX1080 or DX1090, are added dry to the electrolyte. Drying consists in heating the product in a vacuum oven until constant weight is achieved.

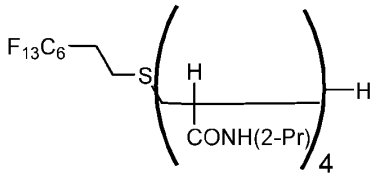
[0071] In some embodiments, the electrolyte additives disclosed herein are represented by a structure with a repeating unit with an integer representing the number of repeating units. See Examples. A person of ordinary skill in the art would understand that the integer is an average

value determined by the stoichiometry between the mercaptan and the polymerizable monomers. The resulting oligomer is not constituted of one defined molecular weight but rather a molecular weight distribution centered around an average value.

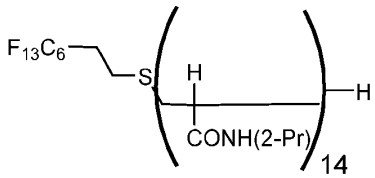
[0072] In some embodiments, the fluorocarbon surfactant as disclosed herein has the structure:

[0073] 

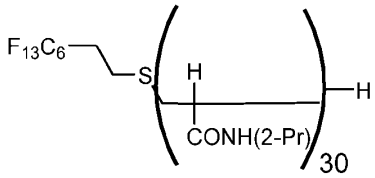
wherein x is from 1 to 40;

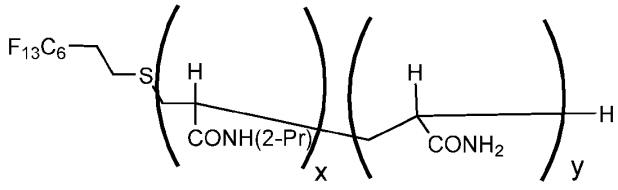
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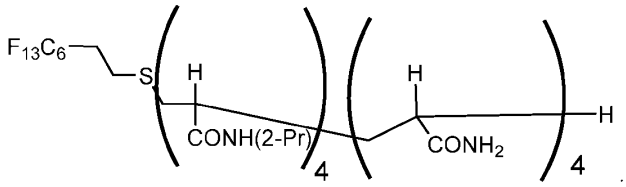
[0075] 

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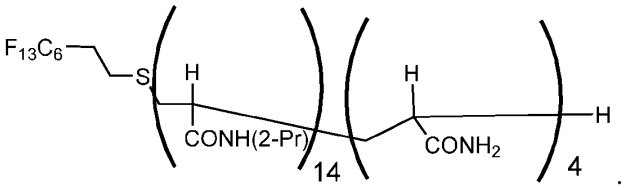
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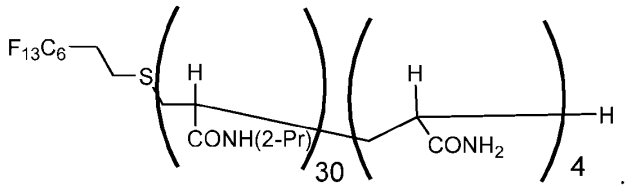
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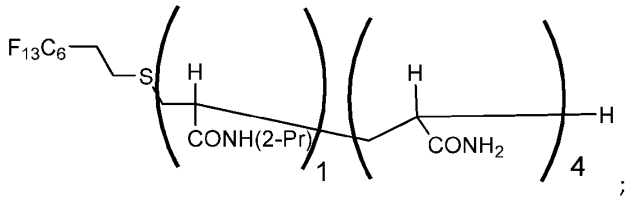
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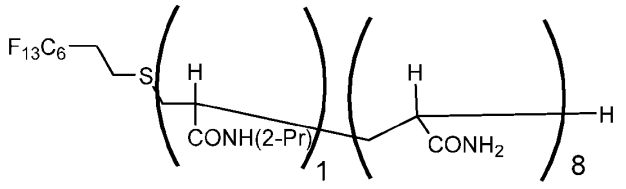
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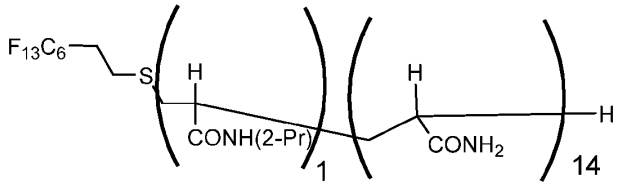
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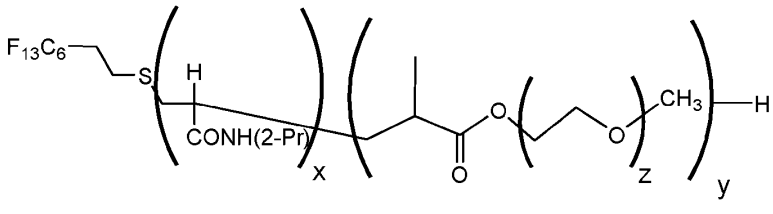
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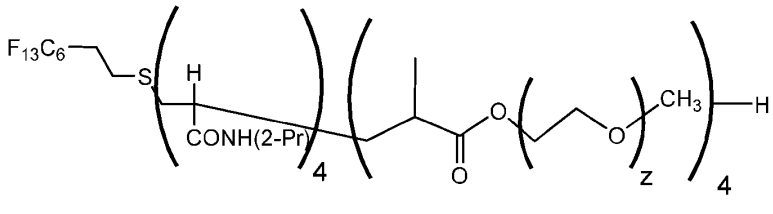
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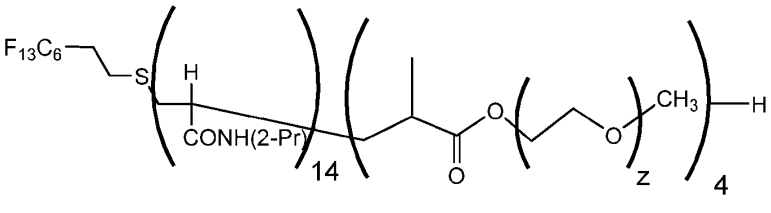
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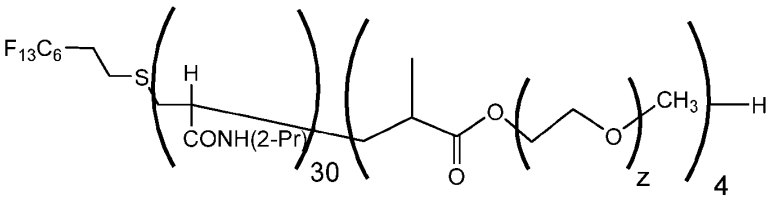
[0082] 

[0083] 

[0084]  wherein x is from 1 to 40, y is from 1 to 40, and z is from 1 to 5; or

[0085]  wherein z is from 4 to 5;

[0086]  wherein z is from 4 to 5;

[0087]  wherein z is from 4 to 5.

Use of R_f-compounds disclosed herein in electrolyte of MIBs

[0088] According to some aspects, the R_f-oligomers disclosed herein (referred to as the "disclosed compounds") are useful as additives to an electrolyte for a MIB, such as a lithium-ion battery. In some embodiments, the disclosed compounds are present in the electrolyte in the

amount of about 0.01%, 0.03%, 0.05%, 0.08%, 0.1%, 0.2%, 0.3%, 0.4%, 0.1%, 0.5%, 0.6%, 0.7%, 0.8% 0.9%, 1%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4%, 4.5%, 5%, 8%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, or 60%, by weight of the electrolyte. In some embodiments, the disclosed compounds are present in the electrolyte in the amount of about 0.001% to 60% by weight of the electrolyte. In some embodiments, the disclosed compounds are present in the electrolyte in the amount of about 4% to 10% by weight of the electrolyte. In some embodiments, the disclosed compounds are present in the electrolyte in the amount of about 20% to 50% by weight of the electrolyte.

[0089] In some embodiments, the compounds disclosed herein added to the electrolyte comprise acrylamide units. In some embodiments, the disclosed compounds added to the electrolyte comprise at least 1, at least 2, at least 3, at least 4, at least 5, at least 6, at least 7, at least 8, at least 9, at least 10, at least 11, at least 12, at least 13, at least 14, at least 15, at least 16, at least 17, at least 18, at least 19, at least 20, at least 21, at least 22, at least 23, at least 24, at least 25, at least 26, at least 27, at least 28, at least 29, or at least 30 acrylamide units per molecule.

Electrolyte salts

[0090] In some embodiments, the electrolytes disclosed herein comprise a salt that is easily dissolved or dissociated in a solvent. In some embodiments, the electrolyte comprises a lithium salt. In some embodiments, the lithium salt is selected from $LiClO_4$, $LiPF_6$, $LiBF_4$, $LiCF_3SO_3$, $LiN(CF_3SO_2)_2$, or combinations thereof. In some embodiments, the electrolyte comprises a magnesium salt. In some embodiments, the magnesium salt is selected from $Mg(TFSI)_2$; $MgSO_4$; MgX_2, where X = halogen; $Mg(trifoliate)_2$; $Mg(RCO_2\text{-})_2$ where R can be methyl, alkyl, halogenated methyl and ethyl; $Mg(B(C_2O_4)_2)_2$; $Mg(BOB)_2$; magnesium titanate@superoxomagnesium titanate; magnesium titanate ($MgTiO_3$); Magnesium dititanate

($MgTi_2O_5$), $[Mg(L)_x]$ $[Al(ORF)_4]_2$ x=3, 6 L= (L=MeCN (acetonitrile), DME (1,2-dimethoxyethane), (ORF= $OCCF_3$); $Mg[B(hfip)_4]_2$, $Mg[B(tftb)_4]_2$, where hexafluoro-tert-isopropoxy is (hfip) and trifluoro-tert-butoxy is (tftb); and the like or combinations thereof. In some embodiments, the electrolyte comprises an aluminum salt. In some embodiments, the aluminum salt is as recited herein for magnesium salts, but the magnesium is substituted with aluminum trivalent. In some embodiments, the aluminum salts are selected from the group consisting of $Al(L)_3$, L= halogen; $(Al(TFSI)_3)$; $(Al(ClO_4)_3)$; $(Al(OTF)_3)$; Al-Zn/$Al(OTF)_3$; or combinations thereof.

Electrolyte solvents

[0091] In some embodiments, the electrolyte comprises an organic solvent that has a high solubility for one or more salts and low viscosity to aid in movement of ions. In some embodiments, the electrolyte comprises an organic solvent that has a high solubility for lithium salt and low viscosity to aid in movement of lithium ions. Such solvents include, for example, cyclic carbonate solvents, chain carbonate solvents, and combinations thereof. In some embodiments, the solvent comprises one or more of dimethyl carbonate, diethyl carbonate, methyl ethyl carbonate, and combinations thereof. In some embodiments, the solvent comprises ethylene carbonate, propylene carbonate, and combinations thereof. In some embodiments, the solvent comprises pyrocarbonates such as dialkyl pyrocarbonates used directly or added to a dialkyl carbonate mix to better control CO_2 evolution. In some embodiments, the solvent comprises ethereal solvents. In some embodiments, the solvent comprises one or more of Tert-Amyl ethyl ether; Cyclopentyl methyl ether; Di-tert-butyl ether; Di(propylene glycol) methyl ether; Dibutyl ether; Diethyl ether; Diisopropyl ether; Dimethoxyethane; Dimethoxymethane; 1,4-Dioxane; Ethyl tert-butyl ether; Methoxyethane; 2-(2-Methoxyethoxy)ethanol; Methyl tert-butyl ether; 2-

Methyltetrahydrofuran; Morpholine; Polyethylene glycol; Propylene glycol methyl ether; Tetrahydrofuran; Tetrahydrofurfuryl alcohol; Tetrahydropyran; 2,2,5,5-Tetramethyltetrahydrofuran, and combinations thereof. In some embodiments, the electrolyte is LP50 electrolyte: 1 M $LiPF_6$ in ethylene carbonate (EC)–ethyl methyl carbonate (EMC) (v/v=1:1).

Other additives

[0092] In some embodiments, the electrolytes comprise additives in addition to the compounds disclosed herein. In some embodiments, the additive is a substance that protects the cathode and/or anode. In some embodiments, cathode additives are included to stabilize the cathode structure and protect the surface to slow battery aging. In some embodiments, anode additives are included to stabilize the anode structure and protect the surface to slow battery aging. In some embodiments, the electrolyte comprises surfactants, SEI forming additives, materials to adjust viscosity, materials to help solubilize salts, and combinations thereof. In some embodiments, the electrolyte comprises cathode protection agents, such as Butylamine, N,N'-dicyclohexylcarbodimide (DCI), Lithium bis(oxalate)boronate (LiBOB), and combinations thereof. In some embodiments, the electrolyte comprises $LIPF_6$ salt stabilizer additives, such as Tris(2,2,2-trifluroethylphosphite (TTFP), 1-methyl2-pyrrolidinone, hexamethyl-phosphoramide, and combinations thereof. In some embodiments, the electrolyte comprises overcharge protector additives, such as Bipyridyl carbonate, Diphenyl carbonate, difluororanisole, thianthrene, 2,7-diacetyl thianthrene, and combinations thereof. In some embodiments, the electrolyte comprises a fire-retardant additive, such as Trimethyl phosphate. In some embodiments, the electrolyte comprises a lithium deposition improver, such as Cetyltrimethylammonium chloride. In some embodiments, the electrolyte comprises an ionic salvation enhancer, such as

tris(pentafluorophenyl)borane (TPFPB). In some embodiments, the electrolyte comprises an Al corrosion inhibitor, such as Lithium bis(oxalate)boronate (LiBOB).

Batteries

[0093] According to some aspects, the present disclosure provides ion batteries comprising a housing and an electric core. The electric core comprises the anode, cathode, and separator, each of which is in contact with an electrolyte. In some embodiments, the negative electrode (anode) is made from a graphite carbon and the positive electrode (cathode) is made from a layered oxide (e.g., lithium cobalt oxide), a polyanion (e.g., lithium iron phosphate) or a spinel (e.g., lithium manganese oxide). In some embodiments disclosed herein, the cathode electrodes are either polycrystalline $LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$ (NMC 532) or single crystalline $LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$ (NMC 721). In some embodiments, the anode electrodes comprise one or more of graphite, lithium, magnesium, and aluminum. In some embodiments, the electrodes are baked in a vacuum under 80 °C for 48 hours to remove moisture. In some embodiments, the housing is a rigid or semi-rigid structure that is effective to prevent the atmosphere and/or moisture from contacting the electric core/electrolyte.

Effects of the disclosed compounds on battery performance

[0094] According to some embodiments, the compounds disclosed herein are added to an electrolyte to improve one or more of the following issues relating to battery performance: dendrite formation, battery lifetime, initial capacity, capacity fade, and wetting time. In some embodiments, the compounds disclosed herein may also have a positive effect on a battery's performance when above or below room temperature.

***Initial Capacity*:**

[0095] In some embodiments, the disclosed compounds herein are effective to increase initial capacity of a battery when added to the electrolyte. The initial capacity is defined

as the capacity of the first cycle. In some embodiments, the disclosed compounds are effective to increase the initial capacity of a MIB by about 1% to about 50%. In some embodiments, the disclosed compounds are effective to increase the initial capacity of a MIB by at least 1%, at least 5%, at least 10%, at least 15%, at least 20%, at least 25%, or at least 30%.

[0096] In some embodiments, the disclosed compounds herein are effective to increase the initial capacity of MIBs comprising high porosity and/or low porosity electrodes. In some embodiments, the disclosed compounds are effective to increase the initial capacity of MIBs comprising single crystal and polycrystalline electrodes. In some embodiments, the disclosed compounds are effective to increase the initial capacity of a battery comprising a polycrystalline $LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$ electrode. In some embodiments, the disclosed compounds are effective to increase the initial capacity from 4.75 Ah to about 5.25 Ah for a battery comprising a polycrystalline $LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$ electrode. In some embodiments, the disclosed compounds are effective to increase the initial capacity from 4.2 Ah to 5.0 Ah for a battery comprising single-crystalline $LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$ electrode.

***Cycling stability / Battery lifetime*:**

[0097] In some embodiments, the disclosed compounds herein are effective to improve cycling stability and battery life when included in the electrolyte. As used herein, the term "cycling" means the process where a battery is charged and discharged to determine how well it holds its charge capacity over many cycles. In some embodiments, the cycling stability is evaluated using a charging/discharging rate of 0.5 C. In some embodiments, the disclosed compounds are effective to maintain at least 90% of initial capacity after at least 100 cycles, at least 200 cycles, at least 300 cycles, at least 400 cycles, or at least 500 cycles. In some embodiments, the disclosed compounds are effective to maintain at least 95% of initial capacity

after at least 100 cycles, at least 200 cycles, at least 300 cycles, at least 400 cycles, or at least 500 cycles.

***Dendrite Suppression*:**

[0098] In some embodiments, the disclosed compounds are effective to decrease dendrite formation when added to an electrolyte. In some embodiments, the disclosed compounds are effective to decrease dendrite formation when added to an electrolyte when the battery is operated under overcharging conditions. In some embodiments, the disclosed compounds are effective to decrease dendrite formation.

Fire Resistance

[0099] In some embodiments, the compounds disclosed herein are effective to decrease or eliminate flammability of the electrolyte relative to flammability of the electrolyte without the compound. In some embodiments, the compounds disclosed herein are effective to self-extinguish an electrolyte after ignition in less than 5 seconds, less than 10 seconds, less than 20 seconds, or less than 30 seconds. In some embodiments, the compounds disclosed herein are effective to prevent ignition of an electrolyte when contacted with a flame.

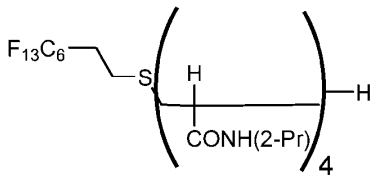
[0100] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used in the specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise.

[0101] The following examples are provided to further illustrate the methods of the present invention. These examples are illustrative only and are not intended to limit the scope of the invention in any way.

EXAMPLES

Example 1: Synthesis of NIPAM derivatives

[0102] *Compound 1:* Perfluoromercapto -(NIPAM)$_4$ Oligomer (Identifier: KF 1-156-1 and KF 2-5-1)

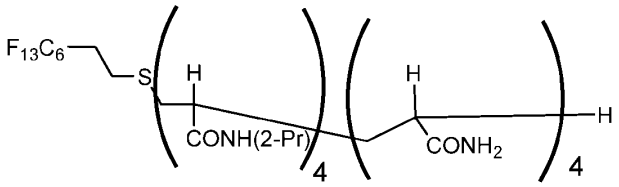


[0103] To a 500 mL glass bottle, at room temperature, were charged N-isopropylacrylamide (29.7 g, 0.26 mol, NIPAM), 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctane-1-thiol, (25.0 g, 0.12 mol) and 2-propanol (150 mL) as solvent. The mixture was stirred to dissolve the mixture and then the solution was purged with nitrogen for 10 minutes. Vazo-52 (0.6 g, 0.002 mol) was added to the mixture and then the solution was purged with nitrogen for an additional 10 minutes. The glass bottle was sealed and transferred to a water bath at 80 – 85°C. The reaction medium was held at 80 – 85°C for 2 hours. The reaction medium was removed from the water bath and transferred to a 500 mL crystallizing dish. The crystalizing dish was placed back into the water bath at 80-85°C to allow the bulk of the solvent to evaporate, and then allowed to cool to ambient temperature overnight in a fume hood to allow the remaining solvent to evaporate. Subsequent drying in a vacuum oven at 50°C/10 mm Hg afforded a white powder (50.7 g, 92%).

[0104] Using the procedure outlined for *Compound 1*, differing only in the stoichiometry of N-isopropylacrylamide (NIPAM) the following oligomers were made:

Compound #	Monomer	Oligomerization (n)	Identifier	Yield (%)
2	$CH_2CHCONH(2\text{-}Pr)$	14	KF 1-157-1 and KF 2-15-1	93.7
3	$CH_2CHCONH(2\text{-}Pr)$	30	KF 2-7-1	97.5

[0105] *Compound 4:* Perfluoromercapto -(NIPAM)$_4$(AA)$_4$ Co-Oligomer (Identifier KF 2-8-1)



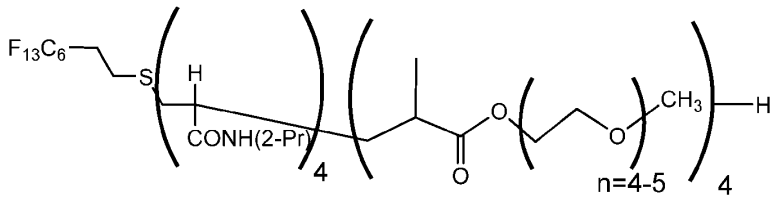
[0106] To a 500 mL glass bottle, at room temperature, were charged N-isopropylacrylamide (14.3 g, 0.13 mol, NIPAM), acrylamide (9.0 g, 0.13 mol, AA) 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctane-1-thiol, (12.0 g, 0.03 mol) and 2-propanol (125 mL) as solvent. The mixture was stirred to dissolve the mixture and then the solution was purged with nitrogen for 10 minutes. Vazo-52 (0.6 g, 0.002 mol) was added to the mixture and then the solution was purged with nitrogen for an additional 10 minutes. The glass bottle was sealed and transferred to a water bath at 80 – 85°C. The reaction medium was held at 80 – 85°C for 2 hours. The reaction medium was removed from the water bath and transferred to a 500 mL crystallizing dish. The crystalizing dish was placed back into the water bath at 80-85°C to allow the bulk of the solvent to evaporate, and then allowed to cool to ambient temperature overnight in a fume hood to allow the remaining solvent to evaporate. Subsequent drying in a vacuum oven at 50°C/10 mm Hg afforded a white powder (34.5 g, 96%).

[0107] Using the procedure outlined for *Compound 4*, differing only in the relative stoichiometry of N-isopropylacrylamide (NIPAM) and acrylamide (AA), the following co-oligomers were made:

Compound #	Monomer 1	oligo-1 (n)	Monomer 2	Oligo-2 (n)	Identifier	Yield (%)
5	$CH_2CHCONH(2\text{-}Pr)$	14	$CH_2CHCONH_2$-	4	KF 2-9-1	98
6	$CH_2CHCONH(2\text{-}Pr)$	30	$CH_2CHCONH_2$-	4	KF 2-10-1	97
7	$CH_2CHCONH(2\text{-}Pr)$	1	$CH_2CHCONH_2$	4	KF 1-160-1	99

8	$CH_2CHCONH(2\text{-}Pr)$	1	$CH_2CHCONH_2$	8	KF 2-4-1	97
9	$CH_2CHCONH(2\text{-}Pr)$	1	$CH_2CHCONH_2$	14	KF 1-161-1	99

[0108] *Compound 10:* Perfluoromercapto -$(NIPAM)_4(MPEG)_4$ Co-Oligomer (identifier KF 2-12-1).



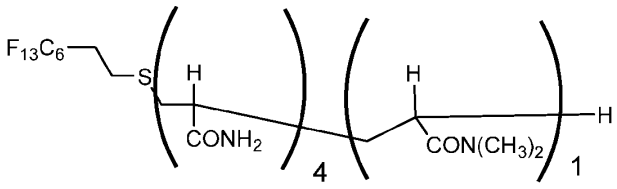
[0109] "MPEG" refers to Poly(ethylene glycol) methyl ether methacrylate with an average molecular weight of 300, corresponding to 4-5 ethylene glycol units per molecule of monomer.

[0110] To a 500 mL glass bottle, at room temperature, were charged N-isopropylacrylamide (7.1 g, 0.06 mol, NIPAM), Poly(ethylene glycol) methyl ether methacrylate (22.1 g, 0.06 mol, MPEG) 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctane-1-thiol, (6.0 g, 0.02 mol) and 2-propanol (125 mL) as solvent. The mixture was stirred to dissolve the mixture and then the solution was purged with nitrogen for 10 minutes. Vazo-52 (0.6 g, 0.002 mol) was added to the mixture and then the solution was purged with nitrogen for an additional 10 minutes. The glass bottle was sealed and transferred to a water bath at 80 – 85°C. The reaction medium was held at 80 – 85°C for 2 hours. The reaction medium was removed from the water bath and transferred to a 500 mL crystallizing dish. The crystalizing dish was placed back into the water bath at 80-85°C to allow the bulk of the solvent to evaporate, and then allowed to cool to ambient temperature overnight in a fume hood to allow the remaining solvent to evaporate. Subsequent drying in a vacuum oven at 50°C/10 mm Hg to afford a clear pale-yellow gel (32.6 g, 91%).

[0111] Using the procedure outlined for *Compound 10*, differing only in the relative stoichiometry of N-isopropylacrylamide (NIPAM) and Poly(ethylene glycol) methyl ether methacrylate (MPEG) the following co-oligomers were made:

Compound #	Monomer 1	oligo-1 (n)	Monomer 2	oligo-2 (n)	Identifier	Yield (%)
11	$CH_2CHCONH(2\text{-}Pr)$	14	$CH_2CH(CH_3)CO_2(CH_2CH_2O)_nCH_3$ n=4-5	4	KF 2-13-1	98
12	$CH_2CHCONH(2\text{-}Pr)$	30	$CH_2CH(CH_3)CO_2(CH_2CH_2O)_nCH_3$ n=4-5	4	KF 2-14-1	97

[0112] *Compound 13:* Perfluoromercapto -$(AA)_4(DMAC)_1$ Co-Oligomer (identifier: KF 1-158-1)



[0113] To a 500 mL glass bottle, at room temperature, were charged acrylamide (34.0 g, 0.47 mol, AA), N, N, dimethylacrylamide (12.0 g, 0.12 mol, DMAC) 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctane-1-thiol, (45 g, 0.12 mol) and 2-propanol (250 mL) as solvent. The mixture was stirred to dissolve the mixture and then the solution was purged with nitrogen for 10 minutes. Vazo-52 (0.6 g, 0.002 mol) was added to the mixture and then the solution was purged with nitrogen for an additional 10 minutes. The glass bottle was sealed and transferred to a water bath at 80 – 85°C. The reaction medium was held at 80 – 85°C for 2 hours. The reaction medium was removed from the water bath and transferred to a 1L crystallizing dish and allowed to cool to ambient temperature in a fume hood for 2-3 days to allow the solvent to evaporate. Subsequent drying in a vacuum oven at 50°C/10 mm Hg to afford a white powder (85.6 g, 94%).

[0114] Using the procedure outlined for *Compound 13*, differing only in the relative stoichiometry of N,N-dimethylacrylamide DMAC) and acrylamide (AA), the following co-oligomers were made:

Compound #	Monomer 1	oligo-1 (n)	Monomer 2	oligo-2 (n)	identifier	Yield (%)
14	$CH_2CHCONH_2$	8	$CH_2CHCON(CH_3)_2)$	1	KF 2-3-1	98
15	$CH_2CHCONH_2$	14	$CH_2CHCON(CH_3)_2)$	1	KF 1-159-1	97

[0115]

Example 2: Battery Experimental Details

[0116] All cells were assembled under argon atmosphere using standard techniques. Standard, commercial electrolyte was purchased from Hefei Fangtiya New material Technology Co., Ltd and used without further purification. Lithium-ion battery pouch cells (standard LFP cathode material, 1.5 Ah capacity, 4.2 V cells) were purchased from Hefei Fangtiya New material Technology Co., Ltd as dry cells (no electrolyte).

[0117] For the preparation of electrolyte gels, additive samples were dried under vacuum at 80°C for 24 hours then cooled to room temperature under argon. Commercial grade-electrolyte was added to the oven-dried additive to generate electrolyte solutions with the desired mass loadings (including loadings of 0.5wt%, 1wt%, 2wt%, 2.5wt%, 5wt%, 10wt%, 33wt%, 40wt%, and 50wt%). In the case of lower mass loadings (less than ~ 33wt%), solutions were stirred under argon atmosphere with a Teflon stir bar for 24 hours to generate homogeneous solutions. In cases of higher mass loadings (33wt% and higher) samples were stirred under argon atmosphere with a Teflon stir bar for 48-72 hours to ensure proper mixing and homogeneity.

[0118] Dry pouch cells were baked at 80°C for 24 hours, then cooled to room temperature and opened under argon atmosphere to load with electrolyte. Cells were allowed to rest to ensure

proper wetting of the separator prior to sealing under vacuum. Sealed cells were allowed to rest for 24 hours prior to aging. Cells were typically aged through a constant current charge at a rate of 0.1C followed by a resting period then a constant current discharge at a rate of 0.1C. Aged cells were transferred to an argon atmosphere where they were opened, replenished with electrolyte solution, and re-sealed using a vacuum sealer.

[0119] Replenished cells then entered a testing protocol with typical voltage range of 2.5 to 4.2 V at a testing rate of 0.5 C. This testing cycle consisted of a constant current charge, followed by a rest, followed by a constant current discharge, followed by a second rest period. Cells were typically tested in short-term cycling studies (1-200 cycles), medium-term cycling studies (200-500 cycles), and long-term cycling studies (up to 1000 cycles).

Example 3: Gel Formation

[0120] Mass loading optimization studies resulted in the discovery of gelation properties at high loadings (>30wt%) in some cases. Mass loadings as high as 50wt% were explored for KF-1-157-1 (n =14 NIPAM derivative) with gelation observed in the case of 33wt%, 40wt%, and 50wt% loading. High mass loading samples were also attempted with KF-1-156-1 (n = 4 NIPAM derivative), which yields solutions with better viscosity for cell assembly. In the case of KF-1-156-1, 33wt% loading resulted in a highly viscous liquid rather than a gel which enabled battery assembly, but this cell performs with somewhat lower capacity retention than control cells. Intermediate mass loadings (2wt%-10wt%) were found to increase electrolyte viscosity, and in some cases these loadings resulted in improved performance relative to control cells.

Example 4: Decreased capacity fade in batteries and increased cycling lifetime

[0121] As shown in Figure 2, when NIPAM derivative is added to electrolyte, batteries cycle with essentially no loss in capacity. Figure 2 shows cycling results at mass loadings of

0.5wt%, 1wt%, 2.5wt%, 5wt%, and 10wt% for additives (a) Compound 1 (KF-1-156-1, n = 4 NIPAM derivative) and (b) Compound 2 (KF-1-157-1, n =14 NIPAM derivative). In all but the 10% loading of Compound 2, these additives improve the cycling lifetime of lithium-ion batteries relative to controls as seen in the cell capacity (Ah) over 1000 charge-discharge cycles.

Example 5: Dendrite suppression and overcharge protection

[0122] As shown in Figure 3, the presence of dendrites was tested for in (a) recovered battery electrolytes and (b) recovered battery separators after long-term cycling studies (1000 cycles). Batteries were opened under argon atmosphere and disassembled to assess dendrite formation. Both Compound 1 (KF-1-156-1, n = 4 NIPAM derivative) and Compound 2 (KF-1-157-1, n =14 NIPAM derivative) effectively suppressed dendrite formation (no dendrites in electrolyte for Compound 1, substantially less dendrites for Compound 2 relative to control cell). Similar observations were found when assessing the separator material.

[0123] As shown in Figure 3(c), overcharge tests were performed wherein cycling results were observed at mass loadings of 2.5wt% for additives Compound 1 (KF-1-156-1, n = 4 NIPAM derivative) and Compound 2 (KF-1-157-1, n =14 NIPAM derivative) during overcharge testing to a voltage of 4.6 V. Additive samples were found to improve overall cell retention over the first 15 cycles relative to a control.

[0124] **Example 6: Efficacious copolymers with NIPAM**

[0125] As seen in Figure 4, cycling results at mass loadings of 2wt%, 5wt%, and 10wt% for Compound 10, $C_6F_3CH_2CH_2$-$(NIPAM)_4(MPEG)_4$-H (identifier: KF-2-12-1) show that copolymers allow for higher mass loadings effective to provide fire protection.

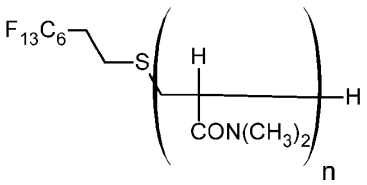
[0126] Table I, below, shows a summary of all additives tested including mass loadings explored and cycling lifetime results. In some cases, additives were found to outperform controls

with improved cycling lifetimes. In some cases, these additives have been explored at various mass loadings. Note: 2-5-1 is the same as 1-156-1 (N 4 NIMPAM) and 2-15-1 is the same as 1-157-1 (n = 14 NIPAM).

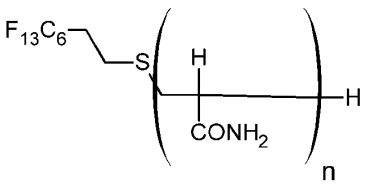
TABLE I

Sample	**Loading tested**	**Summary**
KF-1-154-1	0.5wt%	No improvement over controls
KF-1-155-1	0.5wt%	No improvement over controls
KF-1-156-1	0.5wt%, 1.0wt%, 2.5wt%, 5.0wt%, 10.0wt%, 33.0wt%	Increase in cycling lifetime over controls (except ≥10wt%)
KF-1-157-1	0.5wt%, 1.0wt%, 2.5wt%, 5.0wt%, 10wt%, 33wt%, 40wt%, 50wt%	Increase in cycling lifetime over controls (except ≥33wt%)
KF-1-158-1	0.5wt%	No improvement over controls
KF-1-159-1	0.5wt%	No improvement over controls
KF-1-160-1	0.5wt%	No improvement over controls
KF-1-161-1	0.5wt%	No improvement over controls
KF-2-1-1	5.0wt%	No improvement over controls
KF-2-2-1	5.0wt%	No improvement over controls
KF-2-3-1	5.0wt%	No improvement over controls
KF-2-4-1	5.0wt%	No improvement over controls
KF-2-5-1	2.0wt%, 5.0wt%, 10.0wt%	Increase in cycling lifetime over controls
KF-2-7-1	5.0wt%	No improvement over controls
KF-2-8-1	2.0wt%, 5.0wt%, 10.0wt%	Increase in cycling lifetime over controls (except ≥10wt%)
KF-2-9-1	5.0wt%	Increase in cycling lifetime over controls
KF-2-10-1	5.0wt%	No improvement over controls
KF-2-12-1	2.0wt%, 5.0wt%, 10.0wt%	Increase in cycling lifetime over controls
KF-2-13-1	5.0wt%	No improvement over controls
KF-2-14-1	5.0wt%	Increase in cycling lifetime over controls
KF-2-15-1	5.0wt%	Increase in cycling lifetime over controls

[0127] The sample compounds of Table I are as described above or as follows:



Compound #	Monomer	Oligomerization (n)	Identifier	Yield (%)
16	$CH_2CHCON(CH_3)_2$	4	KF 1-154-1 a	99
17	$CH_2CHCON(CH_3)_2$	14	KF 1-155-1	86.5



Compound #	Monomer	Oligomerization (n)	Identifier	Yield (%)
18	$CH_2CHCONH_2$	2	KF 2-1-1 a	94.6
19	$CH_2CHCONH_2$	3	KF 2-2-1	99.5

Example 7: Fire Resistance

[0128] As show in Figure 5, after ignition the control LP50 electrolyte sustains the fire until full consumption of the fuel (the LP50). The fire burns vigorously until extinguished. See Figure 5(a). In contrast, LP50 comprising 33% of Compound 2 (n =14 NIPAM derivative) ignites the electrolyte when contact with a torch, but the fire self-extinguishes shortly thereafter. See Figure 5(b). Furthermore, LP50 comprising 50% of Compound 2 (n =14 NIPAM derivative) cannot be ignited with a torch and is completely fire resistant. See Figure 5(c).

What is claimed:

1. A fluorocarbon surfactant according to Formula I:

$$R_f–E_n–S–[\text{N-isopropylacrylamide}]_x[M_1]_yH \quad (I)$$

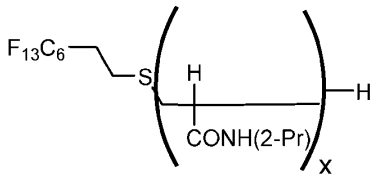
wherein R_f is a straight or branched chain perfluoroalkyl of 4 to 18 carbon atoms, perfluoroalkyloxyalkylene of 5 to 19 carbon atoms, or mixtures thereof; E_n is a straight or branched chain alkylene of 1 to 12 carbon atoms, —CON(R')—E'—, —SO_2N(R')—E'—, —E"—CON(R')—E'—, —E"—S—E'—, —E"—N(R')—E'—; or —E"—SO_2N(R')—E'-, where R' is hydrogen or alkyl of 1 to 6 carbon atoms, E' is alkylene of 2 to 8 carbon atoms and E" is alkylene of 1 to 4 carbon atoms;

[M_1] represents a hydrophilic monomer unit derived from a hydrophilic monomer of the type M_1;

wherein M_1 is optionally more than one type of monomer;

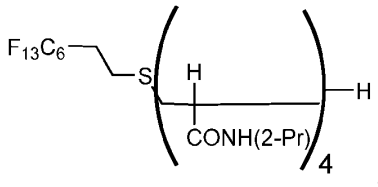
wherein the sum of x and y is between 1 and about 500; x/(x+y) is between 1 and 0.05; and n is 0 or 1.

2. The fluorocarbon surfactant of claim 1, having the structure:

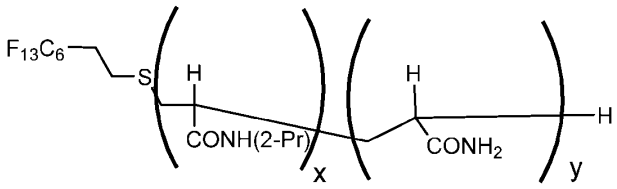


wherein x is from 1 to 40.

3. The fluorocarbon surfactant of claim 1, having the structure:

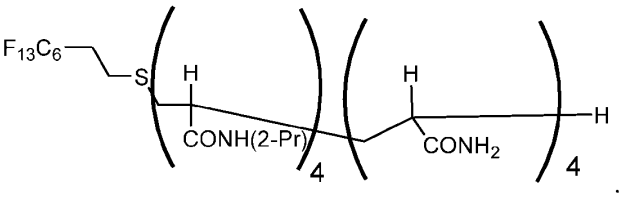


4. The fluorocarbon surfactant of claim 1, having the structure:

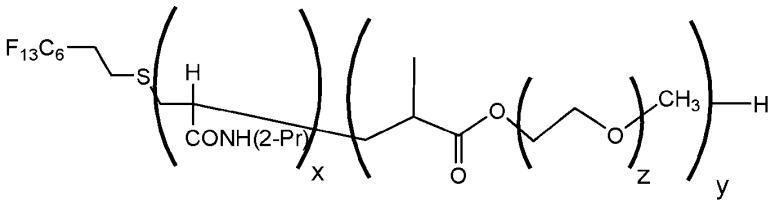


wherein x is from 1 to 40 and y is from 1 to 40.

5. The fluorocarbon surfactant of claim 1, having the structure:

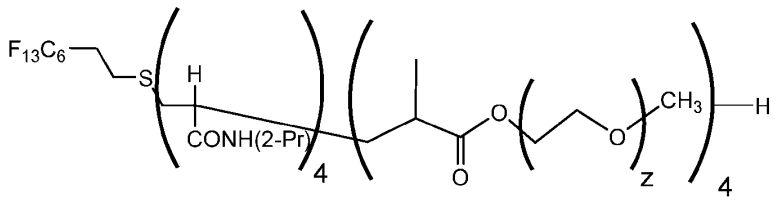


6. The fluorocarbon surfactant of claim 1, having the structure:



wherein x is from 1 to 40, y is from 1 to 40, and z is from 1 to 5.

7. The fluorocarbon surfactant of claim 1, having the structure:



wherein z is from 4 to 5.

8. An ion battery electrolyte comprising an electrolyte salt, a solvent, and at least one fluorocarbon surfactant according to any one of claims 1 to 7.

9. The ion battery electrolyte of claim 8, wherein the electrolyte salt is an electrolyte lithium salt.

10. The ion battery electrolyte of claim 8, wherein the solvent comprises one or more of dimethyl carbonate, diethyl carbonate, methyl ethyl carbonate.

11. An ion battery comprising:

a housing comprising an electric core, and

an electrolyte disposed in said housing,

wherein the electric core is in contact with the electrolyte and the electrolyte comprises at least one fluorocarbon surfactant according to any one of claims 1 to 7.

12. The ion battery of claim 11, wherein the at least one fluorocarbon surfactant according to Formula I comprises about 0.1% to about 60% by weight of the electrolyte.

13. The ion battery of claim 11, wherein the at least one fluorocarbon surfactant according to Formula I comprises about 2% to about 10% by weight of the electrolyte.

14. The ion battery of claim 11, wherein the at least one fluorocarbon surfactant according to Formula I comprises about 33% to about 50% by weight of the electrolyte.

15. The ion battery of claim 11, wherein the ion battery is a lithium-ion battery comprising a lithium salt.

16. The ion battery of claim 11, wherein the lithium salt is selected from $LiClO_4$, $LiPF_6$, $LiBF_4$, $LiCF_3SO_3$, $LiN(CF_3SO_2)_2$, or combinations thereof.

17. The ion battery of claim 11, wherein the electrolyte comprises a solvent selected from dimethyl carbonate, diethyl carbonate, methyl ethyl carbonate, and combinations thereof.

18. A method for improving performance of a metal ion battery comprising the step of contacting the metal ion battery with the ion battery electrolyte of claim 8.

19. The method of claim 18, wherein the improved performance includes improved charge capacity, fade during charge, discharge cycling, and reduced flammability of the metal ion battery relative to a metal ion battery without fluorocarbon surfactant.

20. The method of claim 18, wherein the improved performance includes reduced dendrite formation during charge and discharge cycling of the metal ion battery relative to a metal ion battery without fluorocarbon surfactant.

21. The method of claim 18, wherein the improved performance includes an increased lifetime of the metal ion battery relative to a metal ion battery without fluorocarbon surfactant.

22. The method of claim 18, wherein the metal ion battery is a lithium-ion battery.