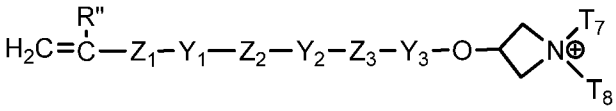
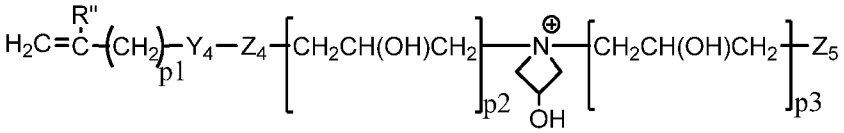
What is claimed is:

1. An azetidinium-containing vinylic monomer, being represented by formula (1) or (2)



(1)



(2)

in which:

R" is hydrogen or methyl;

T_7 and T_8 independent of each other are C_1 to C_{14} alkyl group;

Y_1, Y_2, and Y_3 independent of one other are a linkage selected from the group consisting of a direct bond, –O–, –NR'–, –C(O)–NR'–, –NR'–C(O)–, –O–C(O)–NH–, –NH–C(O)–O–, –NR'–C(O)–NH–, –NH–C(O)–NR'–, –C(O)–O–, –O–C(O)–, –NH–C(O)–NH–Z_0–NH–C(O)–NH–, –O–C(O)–NH–Z_0–NH–C(O)–O–, –O–C(O)–NH–Z_0–NH–C(O)–NH–, and –NH–C(O)–NH–Z_0–NH–C(O)–O–;

R' is hydrogen, a C_1-C_{20} unsubstituted or substituted, linear or branched alkyl group;

Z_0 is a linear or branched C_2-C_{12} alkylene divalent radical or a C_5-C_{45} cycloaliphatic or aliphatic-cycloaliphatic divalent radical optionally containing therein one or more linkages of –O–, –NR'– and –C(O)–, R' is as defined above;

Z_1, Z_2, and Z_3 independent of one other are a direct bond, a C_1-C_{20} unsubstituted or substituted, linear or branched alkylene divalent radical optionally containing therein one or more linkages of –O–, –NR'–, and –C(O)–, a C_1–C_7 alkyleneoxy C_1–C_7 alkylene divalent radical, a divalent radical of –(CH(R")$CH_2O)_{r1}$–CH(R")CH_2– in which R" is as defined above and r1 is an integer of 1 to 20, an unsubstituted phenylene divalent radical, C_1-C_4 alkyl or C_1-C_4 alkoxy substituted phenylene divalent radical or C_7-C_{12} arakylene divalent radical, a C_5-C_{45} cycloaliphatic or aliphatic-cycloaliphatic divalent radical optionally containing therein one or more linkages of –O–, –NR'–,and –C(O)–, a C_6-C_{24} aromatic or araliphatic divalent radical, or combinations thereof;

p1, p2, and p3 independent of one another are zero or 1;

Y_4 is a linkage selected from the group consisting of a direct bond, –O–, –NR'–, –C(O)–NR'–, –NR'–C(O)–, –O–C(O)–NH–, –NH–C(O)–O–, –NR'–

C(O)–NH–, –NH–C(O)–NR'–, –C(O)–O–, –O–C(O)–, R' is hydrogen, a C_1-C_{20} unsubstituted or substituted, linear or branched alkyl group;

Z_4, is a direct bond, a C_1-C_{20} unsubstituted or substituted, linear or branched alkylene divalent radical optionally containing therein one or more linkages of –O–, –NR'–, and –C(O)–, a C_1–C_7 alkyleneoxy C_1–C_7 alkylene divalent radical, or a divalent radical of $–(CH(R'')CH_2O)_{r1}–CH(R'')CH_2–$ in which R'' is as defined above and r1 is an integer of 1 to 20; and

Z_5 is a C_1-C_{20} unsubstituted or substituted, linear or branched alkyl group, $–(CH_2)_{r2}–O–(CH_2CH_2O)_{r1}–Z_6$ in which r1 is as defined above, r2 is zero or an integer of 1 to 7, and Z_6 is a C_1-C_5 alkyl.

2. The azetidinium-containing vinylic monomer of claim 1, being represented by formula (1).
3. The azetidinium-containing vinylic monomer of claim 1, being represented by formula (2).
4. An azetidinium-containing copolymer comprising azetidinium-containing monomeric units derived from at least one azetidinium-containing vinylic monomer of claim 1, 2 or 3, wherein the azetidinium-containing copolymer further comprises monomeric units derived from at least one vinylic monomer selected from the group consisting of a carboxyl-containing vinylic monomer, an amino-containing vinylic monomer, a hydrophobic vinylic monomer, and combination thereof.
5. The azetidinium-containing copolymer of claim 4,

wherein the carboxyl-containing vinylic monomer is selected from the group consisting of acrylic acid, a C_1-C_4-alkyl acrylic acid, N,N-2-acrylamidoglycolic acid, beta methyl-acrylic acid, alpha-phenyl acrylic acid, beta-acryloxy propionic acid, sorbic acid, angelic acid, cinnamic acid, 1-carobxy-4-phenyl butadiene-1,3, itaconic acid, citraconic acid, mesaconic acid, glutaconic acid, aconitic acid, maleic acid, fumaric acid, and combination thereof (preferably selected from the group consisting of acrylic acid, methacrylic acid, ethylacrylic acid, propylacrylic acid, maleic acid, and combinations thereof),

wherein the amino-containing vinylic monomer is selected from the group consisting of amino–C_2-C_4 alkyl (meth)acrylate, allylamine, vinylamine, amino–C_1-C_4 alkyl (meth)acrylamide, N-allyl C_1-C_{12} alkanamine, a coupling reaction product of an epoxy compound having one sole epoxy group (e.g., 1,2-epoxy C_3-C_{12} alkanes, or mono-epoxy terminated polyethyleneglycol) with allylamine, vinylamine, amino–C_2-C_6 alkyl (meth)acrylate, or amino–C_2-C_6 alkyl (meth)acrylamide, a coupling reaction product of an C_1-C_{12} alkanamine or C_2-C_{12} aminoalkanol or with an epoxy-containing vinylic monomer (e.g., glycidyl (meth)acrylate, vinyl glycidyl ether, or allyl glycidyl ether), and

combinations thereof,

wherein the hydrophobic vinylic monomer is selected from the group consisting of methyl (meth)acrylate, ethyl (meth)acrylate, propyl (meth)acrylate, isopropyl (meth)acrylate, butyl (meth)acrylate, sec-butyl (meth)acrylate, isobutyl (meth)acrylate, t-butyl (meth)acrylate, cyclohexylacrylate, 2-ethylhexylacrylate, vinyl acetate, vinyl propionate, vinyl butyrate, vinyl valerate, styrene, chloroprene, vinyl chloride, vinylidene chloride, acrylonitrile, 1-butene, butadiene, methacrylonitrile, vinyl toluene, vinyl ethyl ether, perfluorohexylethyl-thio-carbonyl-aminoethyl-methacrylate, isobornyl methacrylate, trifluoroethyl methacrylate, hexafluoro-isopropyl methacrylate, hexafluorobutyl methacrylate, siloxane-containing vinylic monomer, a polysiloxane-containing vinylic monomer having about 3 to about 40 silicone atoms, and combinations thereof.

6. The azetidinium-containing copolymer of claim 4 or 5, wherein the azetidinium-containing copolymer comprises carboxyl-containing monomeric units derived from a carboxyl-containing vinylic monomer (preferably selected from the group consisting of acrylic acid, methacrylic acid, ethylacrylic acid, propylacrylic acid, maleic acid, and combinations thereof, more preferably selected from the group consisting of methacrylic acid, ethylacrylic acid, and combination thereof, even more preferably derived from methacrylic acid).

7. The azetidinium-containing copolymer of any one of claims 4 to 6, wherein the azetidinium-containing copolymer comprises hydrophobic monomeric units derived from at least one hydrophobic vinylic monomer (preferably selected from the group consisting of methyl (meth)acrylate, ethyl (meth)acrylate, propyl (meth)acrylate, isopropyl (meth)acrylate, butyl (meth)acrylate, sec-butyl (meth)acrylate, isobutyl (meth)acrylate, t-butyl (meth)acrylate, cyclohexylacrylate, 2-ethylhexylacrylate, vinyl acetate, vinyl propionate, vinyl butyrate, vinyl valerate, styrene, chloroprene, vinyl chloride, vinylidene chloride, acrylonitrile, 1-butene, butadiene, methacrylonitrile, vinyl toluene, vinyl ethyl ether, perfluorohexylethyl-thio-carbonyl-aminoethyl-methacrylate, isobornyl methacrylate, trifluoroethyl methacrylate, hexafluoro-isopropyl methacrylate, hexafluorobutyl methacrylate, siloxane-containing vinylic monomer, a polysiloxane-containing vinylic monomer having about 3 to about 40 silicone atoms, and combinations thereof, more preferably selected from the group consisting of at least one siloxane-containing vinylic monomer, at least one polysiloxane-containing vinylic monomer and combinations thereof)

8. The azetidinium-containing copolymer of any one of claims 4 to 7, wherein the azetidinium-containing copolymer comprises amino-containing monomeric units derived from at least one amino-containing vinylic monomer [preferably selected from

the group consisting of amino–C_2-C_4 alkyl (meth)acrylate, allylamine, vinylamine, amino–C_1-C_4 alkyl (meth)acrylamide, N-allyl C_1-C_{12} alkanamine (e.g., N-ethyl-2-methylallylamine, N-ethylallylamine, N-allylmethylamine, N-allyl-1-pentanamine, N-allyl-2-methyl-1-pentanamine, N-allyl-2,3-dimethyl-1-pentanamine, N-allyl-1-hexanamine, N-allyl-2-methyl-1-hexanamine, N-allyl-1-heptanamine, N-allyl-1-octanamine, N-allyl-1-ecanamine, N-allyl-1-dodecanamine), a coupling reaction product of an epoxy compound having one sole epoxy group (e.g., 1,2-epoxy C_3-C_{12} alkanes, or mono-epoxy terminated polyethyleneglycol) with allylamine, vinylamine, amino–C_2-C_6 alkyl (meth)acrylate, or amino–C_2-C_6 alkyl (meth)acrylamide, a coupling reaction product of an C_1-C_{12} alkanamine or C_2-C_{12} aminoalkanol or with an epoxy-containing vinylic monomer (e.g., glycidyl (meth)acrylate, vinyl glycidyl ether, or allyl glycidyl ether), and combinations thereof].

9. The azetidinium-containing copolymer of claim 4, wherein the azetidinium-containing copolymer comprises:

reactive monomeric units which are carboxyl-containing monomeric units and/or amino-containing monomeric units, wherein the carboxyl-containing monomeric units are derived from at least one carboxyl-containing vinylic monomer (preferably selected from the group consisting of acrylic acid, a C_1-C_4-alkyl acrylic acid, N,N-2-acrylamidoglycolic acid, beta methyl-acrylic acid, alpha-phenyl acrylic acid, beta-acryloxy propionic acid, sorbic acid, angelic acid, cinnamic acid, 1-carobxy-4-phenyl butadiene-1,3, itaconic acid, citraconic acid, mesaconic acid, glutaconic acid, aconitic acid, maleic acid, fumaric acid, and combination thereof, more preferably selected from the group consisting of acrylic acid, methacrylic acid, ethylacrylic acid, propylacrylic acid, maleic acid, and combinations thereof, even more preferably selected from the group consisting of methacrylic acid, ethylacrylic acid, and combination thereof, most preferably derived from methacrylic acid) and wherein the amino-containing vinylic monomeric units are derived from at least one amino-containing vinylic monomer [preferably selected from the group consisting of amino–C_2-C_4 alkyl (meth)acrylate, allylamine, vinylamine, amino–C_1-C_4 alkyl (meth)acrylamide, N-allyl C_1-C_{12} alkanamine, a coupling reaction product of an epoxy compound having one sole epoxy group (e.g., 1,2-epoxy C_3-C_{12} alkanes, or mono-epoxy terminated polyethyleneglycol) with allylamine, vinylamine, amino–C_2-C_6 alkyl (meth)acrylate, or amino–C_2-C_6 alkyl (meth)acrylamide, a coupling reaction product of an C_1-C_{12} alkanamine or C_2-C_{12} aminoalkanol or with an epoxy-containing vinylic monomer (e.g., glycidyl (meth)acrylate, vinyl glycidyl ether, or allyl glycidyl ether), and combinations thereof]; and

at least about 50%, preferably at least about 60%, more preferably at least about 70%,

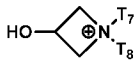
even more preferably at least about 75% by moles of non-reactive hydrophilic monomeric units derived from at least one hydrophilic vinylic monomer selected from the group consisting of (meth)acrylamide, N,N-dimethyl (meth)acrylamide, N-vinylpyrrolidone, N,N,-dimethylaminoethyl (meth)acrylate, N,N-dimethylaminopropyl (meth)acrylamide, glycerol methacrylate, 3-acryloylamino-1-propanol, N-hydroxyethyl acrylamide, *N*-[tris(hydroxymethyl)methyl]-acrylamide, N-methyl-3-methylene-2-pyrrolidone, 1-ethyl-3-methylene-2-pyrrolidone, 1-methyl-5-methylene-2-pyrrolidone, 1-ethyl-5-methylene-2-pyrrolidone, 5-methyl-3-methylene-2-pyrrolidone, 5-ethyl-3-methylene-2-pyrrolidone, 2-hydroxyethyl (meth)acrylate, hydroxypropyl (meth)acrylate, C_1-C_4-alkoxy polyethylene glycol (meth)acrylate having a weight average molecular weight of up to 1500 Daltons, N-vinyl formamide, N-vinyl acetamide, N-vinyl isopropylamide, N-vinyl-N-methyl acetamide, allyl alcohol, vinyl alcohol (hydrolyzed form of vinyl acetate in the copolymer), a phosphorylcholine-containing vinylic monomer, erythritol (meth)acrylate, arabitol (meth)acrylate, mannitol (meth)acrylate, ducitol (meth)acrylate, fucitol (meth)acrylate, iditol (meth)acrylate, innositol (meth)acrylate, xylitol (meth)acrylate, sorbitol (meth)acrylate, glucose (meth)acrylate, fructose (meth)acrylate, galactose (meth)acrylate, and combinations thereof (preferably selected from the group consisting of (meth)acrylamide, N,N-dimethyl (meth)acrylamide, N-vinylpyrrolidone, N,N,-dimethylaminoethyl (meth)acrylate, glycerol methacrylate, 3-acryloylamino-1-propanol, N-hydroxyethyl acrylamide, *N*-[tris(hydroxymethyl)methyl]-acrylamide, N-methyl-3-methylene-2-pyrrolidone, 1-ethyl-3-methylene-2-pyrrolidone, 1-methyl-5-methylene-2-pyrrolidone, 1-ethyl-5-methylene-2-pyrrolidone, 5-methyl-3-methylene-2-pyrrolidone, 5-ethyl-3-methylene-2-pyrrolidone, 2-hydroxyethyl (meth)acrylate, C_1-C_4-alkoxy polyethylene glycol (meth)acrylate having a weight average molecular weight of up to 1500 Daltons, N-vinyl formamide, N-vinyl acetamide, N-vinyl-N-methyl acetamide, allyl alcohol, a phosphorylcholine-containing vinylic monomer, erythritol (meth)acrylate, arabitol (meth)acrylate, mannitol (meth)acrylate, ducitol (meth)acrylate, fucitol (meth)acrylate, iditol (meth)acrylate, innositol (meth)acrylate, xylitol (meth)acrylate, sorbitol (meth)acrylate, glucose (meth)acrylate, fructose (meth)acrylate, galactose (meth)acrylate, and combinations thereof).

10. The azetidinium-containing copolymer of claim 9, wherein the azetidinium-containing copolymer comprises up to about 50%, preferably from about 2.5% to about 40%, more preferably from about 5% to about 30%, even more preferably from about 7.5% to about 25% by moles of the azetidinium-containing monomeric units and the reactive monomeric units.

11. A method for producing coated silicone hydrogel contact lenses each having a crosslinked hydrophilic coating thereon, comprising the steps of:
(a) obtaining a silicone hydrogel contact lens;
(b) applying a prime coating of an anchoring polymer onto the silicone hydrogel contact lens, wherein the anchoring polymer is
(i) an azetidinium-containing copolymer of any one of claims 4 to 8, and/or
(ii) a homopolymer or copolymer of a carboxyl-containing vinylic monomer; and
(c) heating the silicone hydrogel contact lens in an aqueous solution in the presence of a water-soluble, thermally-crosslinkable hydrophilic polymeric material comprising reactive functional groups selected from the group consisting of azetidinium groups, carboxyl groups, amino groups, thiol groups and combinations thereof, to and at a temperature from about 40°C to about 140°C for a period of time sufficient to induce intermolecular and intramolecular crosslinking reaction between one azetidinium group and one amino or carboxyl group, thereby forming a durable non-silicone hydrogel coating on the silicone hydrogel contact lens,
provided that at least one of the anchoring polymer and the thermally-crosslinkable hydrophilic polymeric material comprises azetidinium groups.

12. A method for producing silicone hydrogel contact lenses each having a crosslinked hydrophilic coating thereon, comprising the steps of:
(a) obtaining a silicone hydrogel contact lens by polymerization in a mold of a lens-forming composition comprising an azetidinium-containing vinylic monomer of claim 1, 2 or 3, and/or an azetidinium-containing copolymer of claim 7 or 8;
(b) heating the obtained silicone hydrogel contact lens in an aqueous solution in the presence of a water-soluble, thermally-crosslinkable hydrophilic polymeric material comprising reactive functional groups selected from the group consisting of azetidinium groups, carboxyl groups, amino groups, thiol groups and combinations thereof, to and at a temperature from about 40°C to about 140°C for a period of time sufficient to induce intermolecular and intramolecular crosslinking reactions between one azetidinium group and one amino or carboxyl group, thereby forming a durable non-silicone hydrogel coating on the silicone hydrogel contact lens, wherein the non-silicone hydrogel coating is anchored onto the silicone hydrogel contact lens through the azetidinium groups of the azetidinium-containing copolymer on and/or near the surface of the silicone hydrogel contact lens.

13. The method of claim 12, further comprising a step of applying a prime coating of an anchoring polymer onto the silicone hydrogel contact lens, wherein the anchoring polymer is (i) an azetidinium-containing copolymer of any one of claims 4 to 8, and/or (ii) a homopolymer or copolymer of a carboxyl-containing vinylic monomer.

14. The method of claim 11 or 13, wherein the anchoring polymer is: polyacrylic acid; polymethacrylic acid; polyethylacrylic acid, polypropylacrylic acid; a copolymer of at least two vinylic monomers selected from the group consisting of acrylic acid, methacrylic acid, ethylacrylic acid, and propylacrylic acid; polymaleic acid (i.e., partially or fully hydrolyzed polymaleic anhydride); a copolymer of maleic acid and one or more vinylic monomers (e.g., ethylene, methyl vinyl ether, vinyl acetate, and/or isobutylene); a copolymer composed of from about 0.05% to about 20% (preferably from about 0.1% to about 15%, more preferably from about 0.5% to about 10%) by moles of the azetidinium-containing vinylic monomer and of from about 80% to about 99.95% by moles of one or more carboxyl-containing vinylic monomers selected from the group consisting of acrylic acid, methacrylic acid, ethylacrylic acid, propylacrylic acid, and combination thereof; a reaction product of an azetidinium compound of  in which T_7 and T_8 as defined in claim 1 with polymaleic anhydride or with a copolymer of maleic anhydride and one or more vinylic monomers (e.g., ethylene, methyl vinyl ether, vinyl acetate, and/or isobutylene), wherein the molar equivalent ratio of the azetidinium compound to maleic anhydride is about 0.25 or less (preferably about 0.2 or less, more preferably about 0.15 or less, even more preferably about 0.1 or less); or a combination thereof.

15. The method of claim 11, 13 or 14, wherein the anchoring polymer is: polymethacrylic acid; polyethylacrylic acid, a copolymer of methacrylic acid and ethylacrylic acid; polymaleic acid (i.e., partially or fully hydrolyzed polymaleic anhydride); a copolymer composed of from about 0.05% to about 20% (preferably from about 0.1% to about 15%, more preferably from about 0.5% to about 10%) by moles of the azetidinium-containing vinylic monomer and of from about 80% to about 99.95% by moles of one or more carboxyl-containing vinylic monomers selected from the group consisting of methacrylic acid, ethylacrylic acid, and combination thereof; or a combination thereof.

16. The method of claim 11 or 13, wherein the anchoring polymer is an azetidinium-containing copolymer of any one of claims 4 to 8.

17. The method of any one of claims 11 to 16, wherein the thermally-crosslinkable hydrophilic polymeric material is:

(i) an azetidinium-containing copolymer of claim 9 or 10;

(ii) a reaction product of an azetidinium-containing copolymer of claim 9 or 10 with at least one hydrophilicity-enhancing agent having at least one reactive functional group selected from the group consisting of amino group, carboxyl group, thiol group, and combinations thereof;

(iii) a reaction product of polyaminoamide-epichlorohydrin with at least one hydrophilicity-enhancing agent having at least one reactive functional group selected from the group consisting of amino group, carboxyl group, thiol group, and combinations thereof;

(iv) a water-soluble hydrophilic polymer having at least one reactive functional group selected from the group consisting of amino group, carboxyl group, thiol group, and combinations thereof; or

(v) combinations thereof.

18. The method of any one of claims 11 to 17, wherein the step of heating is performed by autoclaving the silicone hydrogel contact lens immersed in a packaging solution in a sealed lens package at a temperature of from about 118°C to about 125°C for approximately 20-90 minutes.

19. The method of claim 18, wherein the packaging solution comprises from about 0.01% to about 2%, preferably from about 0.05% to about 1.5%, more preferably from about 0.1% to about 1%, even more preferably from about 0.2% to about 0.5%, by weight of the thermally-crosslinkable hydrophilic polymeric material.

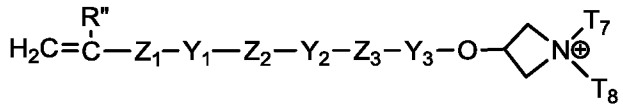
20. A silicone hydrogel contact lens obtained according to a method of any one of claims 11-19, wherein the silicone hydrogel contact lens has an oxygen permeability of at least about 40 barrers, a surface wettability characterized by a water contact angle of about 100 degrees or less, and a good coating durability characterized by surviving a digital rubbing test.

Claims

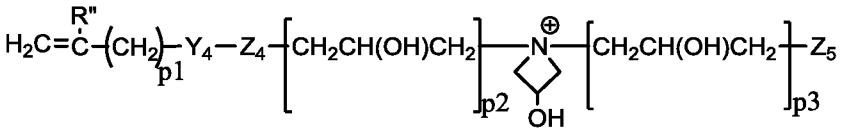
1. An azetidinium-containing copolymer comprising:

(a) monomeric units derived from at least one vinylic monomer selected from the group consisting of a carboxyl-containing vinylic monomer, an amino-containing vinylic monomer, and combination thereof; and

(b) azetidinium-containing monomeric units derived from at least one azetidinium-containing vinylic monomer of formula (1) or (2)



(1)



(2)

in which:

R" is hydrogen or methyl;

T_7 and T_8 independent of each other are C_1 to C_{14} alkyl group;

Y_1, Y_2, and Y_3 independent of one other are a linkage selected from the group consisting of a direct bond, –O–, –NR'–, –C(O)–NR'–, –NR'–C(O)–, –O–C(O)–NH–, –NH–C(O)–O–, –NR'–C(O)–NH–, –NH–C(O)–NR'–, –C(O)–O–, –O–C(O)–, –NH–C(O)–NH–Z_0–NH–C(O)–NH–, –O–C(O)–NH–Z_0–NH–C(O)–O–, –O–C(O)–NH–Z_0–NH–C(O)–NH–, and –NH–C(O)–NH–Z_0–NH–C(O)–O–;

R' is hydrogen, a C_1-C_{20} unsubstituted or substituted, linear or branched alkyl group;

Z_0 is a linear or branched C_2-C_{12} alkylene divalent radical or a C_5-C_{45} cycloaliphatic or aliphatic-cycloaliphatic divalent radical optionally containing therein one or more linkages of –O–, –NR'– and –C(O)–, R' is as defined above;

Z_1, Z_2, and Z_3 independent of one other are a direct bond, a C_1-C_{20} unsubstituted or substituted, linear or branched alkylene divalent radical optionally containing therein one or more linkages of –O–, –NR'–, and –C(O)–, a C_1–C_7 alkyleneoxy C_1–C_7 alkylene divalent radical, a divalent radical of –(CH(R")$CH_2O)_{r1}$–CH(R")CH_2– in which R" is as defined above and r1 is an integer of 1 to 20, an unsubstituted phenylene divalent radical, C_1-C_4 alkyl or C_1-C_4 alkoxy substituted phenylene divalent radical or C_7-C_{12} arakylene divalent radical, a C_5-C_{45} cycloaliphatic or aliphatic-cycloaliphatic divalent radical optionally containing therein one or more linkages of –O–, –NR'–,and –C(O)–, a C_6-C_{24} aromatic or araliphatic divalent radical, or combinations

thereof;

p1, p2, and p3 independent of one another are zero or 1;

Y_4 is a linkage selected from the group consisting of a direct bond, –O–, –NR'–, –C(O)–NR'–, –NR'–C(O)–, –O–C(O)–NH–, –NH–C(O)–O–, –NR'–C(O)–NH–, –NH–C(O)–NR'–, –C(O)–O–, –O–C(O)–, R' is hydrogen, a C_1-C_{20} unsubstituted or substituted, linear or branched alkyl group;

Z_4, is a direct bond, a C_1-C_{20} unsubstituted or substituted, linear or branched alkylene divalent radical optionally containing therein one or more linkages of –O–, –NR'–, and –C(O)–, a C_1–C_7 alkyleneoxy C_1–C_7 alkylene divalent radical, or a divalent radical of $–(CH(R'')CH_2O)_{r1}–CH(R'')CH_2–$ in which R'' is as defined above and r1 is an integer of 1 to 20; and

Z_5 is a C_1-C_{20} unsubstituted or substituted, linear or branched alkyl group, $–(CH_2)_{r2}–O–(CH_2CH_2O)_{r1}–Z_6$ in which r1 is as defined above, r2 is zero or an integer of 1 to 7, and Z_6 is a C_1-C_5 alkyl.

2. The azetidinium-containing copolymer of claim 1, comprising monomeric units of azetidinium-containing vinylic monomer of formula (1).

3. The azetidinium-containing copolymer of claim 1, comprising monomeric units of azetidinium-containing vinylic monomer of formula (2).

4. The azetidinium-containing copolymer of claim 1, 2 or 3,
wherein the carboxyl-containing vinylic monomer is selected from the group consisting of acrylic acid, a C_1-C_4-alkyl acrylic acid, N,N-2-acrylamidoglycolic acid, beta methyl-acrylic acid, alpha-phenyl acrylic acid, beta-acryloxy propionic acid, sorbic acid, angelic acid, cinnamic acid, 1-carobxy-4-phenyl butadiene-1,3, itaconic acid, citraconic acid, mesaconic acid, glutaconic acid, aconitic acid, maleic acid, fumaric acid, and combination thereof ,
wherein the amino-containing vinylic monomer is selected from the group consisting of amino–C_2-C_4 alkyl (meth)acrylate, allylamine, vinylamine, amino–C_1-C_4 alkyl (meth)acrylamide, N-allyl C_1-C_{12} alkanamine, a coupling reaction product of an epoxy compound having one sole epoxy group with allylamine, vinylamine, amino–C_2-C_6 alkyl (meth)acrylate, or amino–C_2-C_6 alkyl (meth)acrylamide, a coupling reaction product of an C_1-C_{12} alkanamine or C_2-C_{12} aminoalkanol or with an epoxy-containing vinylic monomer , and combinations thereof.

5. The azetidinium-containing copolymer of any one of claims 1 to 4, wherein the

azetidinium-containing copolymer comprises carboxyl-containing monomeric units derived from a carboxyl-containing vinylic monomer selected from the group consisting of methacrylic acid, ethylacrylic acid, and combination thereof.

6. The azetidinium-containing copolymer of any one of claims 1 to 5, wherein the azetidinium-containing copolymer comprises amino-containing monomeric units derived from at least one amino-containing vinylic monomer selected from the group consisting of amino–C_2-C_4 alkyl (meth)acrylate, allylamine, vinylamine, amino–C_1-C_4 alkyl (meth)acrylamide, N-allyl C_1-C_{12} alkanamine , a coupling reaction product of an epoxy compound having one sole epoxy group with allylamine, vinylamine, amino–C_2-C_6 alkyl (meth)acrylate, or amino–C_2-C_6 alkyl (meth)acrylamide, a coupling reaction product of an C_1-C_{12} alkanamine or C_2-C_{12} aminoalkanol or with an epoxy-containing vinylic monomer , and combinations thereof.

7. The azetidinium-containing copolymer of any one of claims 1 to 3, wherein the azetidinium-containing copolymer comprises:
reactive monomeric units which are carboxyl-containing monomeric units and/or amino-containing monomeric units, wherein the carboxyl-containing monomeric units are derived from at least one carboxyl-containing vinylic monomer selected from the group consisting of acrylic acid, a C_1-C_4-alkyl acrylic acid, N,N-2-acrylamidoglycolic acid, beta methyl-acrylic acid, alpha-phenyl acrylic acid, beta-acryloxy propionic acid, sorbic acid, angelic acid, cinnamic acid, 1-carobxy-4-phenyl butadiene-1,3, itaconic acid, citraconic acid, mesaconic acid, glutaconic acid, aconitic acid, maleic acid, fumaric acid, and combination thereof, and wherein the amino-containing vinylic monomeric units are derived from at least one amino-containing vinylic monomer selected from the group consisting of amino–C_2-C_4 alkyl (meth)acrylate, allylamine, vinylamine, amino–C_1-C_4 alkyl (meth)acrylamide, N-allyl C_1-C_{12} alkanamine, a coupling reaction product of an epoxy compound having one sole epoxy group with allylamine, vinylamine, amino–C_2-C_6 alkyl (meth)acrylate, or amino–C_2-C_6 alkyl (meth)acrylamide, a coupling reaction product of an C_1-C_{12} alkanamine or C_2-C_{12} aminoalkanol or with an epoxy-containing vinylic monomer , and combinations thereof; and
at least 50%, by moles of non-reactive hydrophilic monomeric units derived from at least one hydrophilic vinylic monomer selected from the group consisting of (meth)acrylamide, N,N-dimethyl (meth)acrylamide, N-vinylpyrrolidone, N,N,-dimethylaminoethyl (meth)acrylate, N,N-dimethylaminopropyl (meth)acrylamide, glycerol methacrylate, 3-acryloylamino-1-propanol, N-hydroxyethyl acrylamide, *N*-[tris(hydroxymethyl)methyl]-acrylamide, N-methyl-3-methylene-2-pyrrolidone, 1-ethyl-3-

methylene-2-pyrrolidone, 1-methyl-5-methylene-2-pyrrolidone, 1-ethyl-5-methylene-2-pyrrolidone, 5-methyl-3-methylene-2-pyrrolidone, 5-ethyl-3-methylene-2-pyrrolidone, 2-hydroxyethyl (meth)acrylate, hydroxypropyl (meth)acrylate, C_1-C_4-alkoxy polyethylene glycol (meth)acrylate having a weight average molecular weight of up to 1500 Daltons, N-vinyl formamide, N-vinyl acetamide, N-vinyl isopropylamide, N-vinyl-N-methyl acetamide, allyl alcohol, vinyl alcohol , a phosphorylcholine-containing vinylic monomer, erythritol (meth)acrylate, arabitol (meth)acrylate, mannitol (meth)acrylate, ducitol (meth)acrylate, fucitol (meth)acrylate, iditol (meth)acrylate, innositol (meth)acrylate, xylitol (meth)acrylate, sorbitol (meth)acrylate, glucose (meth)acrylate, fructose (meth)acrylate, galactose (meth)acrylate, and combinations thereof.

8. The azetidinium-containing copolymer of claim 7, wherein the azetidinium-containing copolymer comprises up to about 50% by moles of the azetidinium-containing monomeric units and the reactive monomeric units.

9. A method for producing coated silicone hydrogel contact lenses each having a crosslinked hydrophilic coating thereon, comprising the steps of:

(a) obtaining a silicone hydrogel contact lens;

(b) applying a prime coating of an anchoring polymer onto the silicone hydrogel contact lens, wherein the anchoring polymer is

(i) an azetidinium-containing copolymer of any one of claims 1 to 6; and

(c) heating the silicone hydrogel contact lens in an aqueous solution in the presence of a water-soluble, thermally-crosslinkable hydrophilic polymeric material comprising reactive functional groups selected from the group consisting of azetidinium groups, carboxyl groups, amino groups, thiol groups and combinations thereof, to and at a temperature from about 40°C to about 140°C for a period of time sufficient to induce intermolecular and intramolecular crosslinking reaction between one azetidinium group and one amino or carboxyl group, thereby forming a durable non-silicone hydrogel coating on the silicone hydrogel contact lens.

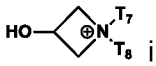
10. A method for producing silicone hydrogel contact lenses each having a crosslinked hydrophilic coating thereon, comprising the steps of:

(a) obtaining a silicone hydrogel contact lens by polymerization in a mold of a lens-forming composition comprising an azetidinium-containing copolymer of claim 6;

(b) heating the obtained silicone hydrogel contact lens in an aqueous solution in the presence of a water-soluble, thermally-crosslinkable hydrophilic polymeric material comprising reactive functional groups selected from the group consisting of

azetidinium groups, carboxyl groups, amino groups, thiol groups and combinations thereof, to and at a temperature from about 40°C to about 140°C for a period of time sufficient to induce intermolecular and intramolecular crosslinking reactions between one azetidinium group and one amino or carboxyl group, thereby forming a durable non-silicone hydrogel coating on the silicone hydrogel contact lens, wherein the non-silicone hydrogel coating is anchored onto the silicone hydrogel contact lens through the azetidinium groups of the azetidinium-containing copolymer on and/or near the surface of the silicone hydrogel contact lens.

11. The method of claim 10, further comprising a step of applying a prime coating of an anchoring polymer onto the silicone hydrogel contact lens, wherein the anchoring polymer is (i) an azetidinium-containing copolymer of any one of claims 1 to 6, and/or (ii) a homopolymer or copolymer of a carboxyl-containing vinylic monomer.

12. The method of claim 11, wherein the anchoring polymer is: polyacrylic acid; polymethacrylic acid; polyethylacrylic acid, polypropylacrylic acid; a copolymer of at least two vinylic monomers selected from the group consisting of acrylic acid, methacrylic acid, ethylacrylic acid, and propylacrylic acid; polymaleic acid ; a copolymer of maleic acid and one or more vinylic monomers ; a copolymer composed of from about 0.05% to about 20% by moles of the azetidinium-containing vinylic monomer and of from about 80% to about 99.95% by moles of one or more carboxyl-containing vinylic monomers selected from the group consisting of acrylic acid, methacrylic acid, ethylacrylic acid, propylacrylic acid, and combination thereof; a reaction product of an azetidinium compound of  in which T_7 and T_8 as defined in claim 1 with polymaleic anhydride or with a copolymer of maleic anhydride and one or more vinylic monomers , wherein the molar equivalent ratio of the azetidinium compound to maleic anhydride is about 0.25 or less; or a combination thereof.

13. The method of claim 9, 11 or 12, wherein the anchoring polymer is a copolymer composed of from about 0.05% to about 20% by moles of the azetidinium-containing vinylic monomer and of from about 80% to about 99.95% by moles of one or more carboxyl-containing vinylic monomers selected from the group consisting of methacrylic acid, ethylacrylic acid, and combination thereof; or a combination thereof.

14. The method of any one of claims 9 to13, wherein the thermally-crosslinkable

hydrophilic polymeric material is:

(i) an azetidinium-containing copolymer of claim 7 or 8;

(ii) a reaction product of an azetidinium-containing copolymer of claim 7 or 8 with at least one hydrophilicity-enhancing agent having at least one reactive functional group selected from the group consisting of amino group, carboxyl group, thiol group, and combinations thereof;

(iii) a reaction product of polyaminoamide-epichlorohydrin with at least one hydrophilicity-enhancing agent having at least one reactive functional group selected from the group consisting of amino group, carboxyl group, thiol group, and combinations thereof;

(iv) a water-soluble hydrophilic polymer having at least one reactive functional group selected from the group consisting of amino group, carboxyl group, thiol group, and combinations thereof; or

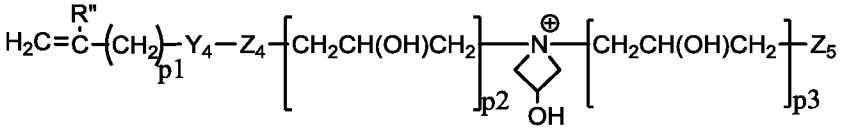
(v) combinations thereof.

15. The method of any one of claims 9 to 14, wherein the step of heating is performed by autoclaving the silicone hydrogel contact lens immersed in a packaging solution in a sealed lens package at a temperature of from about 118°C to about 125°C for approximately 20-90 minutes.

16. The method of claim 15, wherein the packaging solution comprises from about 0.01% to about 2% by weight of the thermally-crosslinkable hydrophilic polymeric material.

17. A silicone hydrogel contact lens obtained according to a method of any one of claims 9 to 16, wherein the silicone hydrogel contact lens has an oxygen permeability of at least about 40 barrers, a surface wettability characterized by a water contact angle of about 100 degrees or less, and a good coating durability characterized by surviving a digital rubbing test.

18. An azetidinium-containing vinylic monomer of formula (2)



(2)

in which:

R" is hydrogen or methyl;

p1, p2, and p3 independent of one another are zero or 1;

Y_4 is a linkage selected from the group consisting of a direct bond, –O–, –

NR'–, –C(O)–NR'–, –NR'–C(O)–, –O–C(O)–NH–, –NH–C(O)–O–, –NR'–C(O)–NH–, –NH–C(O)–NR'–, –C(O)–O–, –O–C(O)–, R' is hydrogen, a C_1-C_{20} unsubstituted or substituted, linear or branched alkyl group;

Z_4, is a direct bond, a C_1-C_{20} unsubstituted or substituted, linear or branched alkylene divalent radical optionally containing therein one or more linkages of –O–, –NR'–, and –C(O)–, a C_1–C_7 alkyleneoxy C_1–C_7 alkylene divalent radical, or a divalent radical of $–(CH(R'')CH_2O)_{r1}–CH(R'')CH_2–$ in which R'' is as defined above and r1 is an integer of 1 to 20; and

Z_5 is a C_1-C_{20} unsubstituted or substituted, linear or branched alkyl group, $–(CH_2)_{r2}–O–(CH_2CH_2O)_{r1}–Z_6$ in which r1 is as defined above, r2 is zero or an integer of 1 to 7, and Z_6 is a C_1-C_5 alkyl.