as layer-by-layer deposition that are suitable for laboratory research but not practical when the process is scaled up.

There is therefore a need to provide an antimicrobial coating that overcomes or at least ameliorates, one or more of the disadvantages described above.

Summary

There is provided a polymer having a plurality of pendant groups, wherein the pendant groups comprise: a first pendant group comprising a quaternary ammonium component having the following formula: $-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$; wherein n is any integer from 1 to 18; R^1 is C(O)O or C(O)NH; R^2, R^3 and R^4 are each independently an optionally substituted alkyl, optionally substituted aryl, or R^2 and $R^3$are taken together to form a ring and R^4 is H or absent; and X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and a second pendant group comprising an organosilane component, provided that there are no other pendant groups in the polymer.

In an aspect, there is provided a polymer having a plurality of pendant groups, wherein the pendant groups comprise: a first pendant group comprising a quaternary ammonium component having the following formula: $-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$; wherein n is any integer from 1 to 18; R^1 is C(O)O or C(O)NH; R^2 and R^3 are each independently an optionally substituted alkyl or optionally substituted aryl and R^4 is an optionally substituted C_{14} to C_{24} alkyl, or R^2 and $R^3$are taken together to form a ring and R^4 is H or absent; and X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and a second pendant group comprising an organosilane component, provided that there are no other pendant groups in the polymer.

There is provided a polymer having a plurality of pendant groups, wherein the pendant groups consists of: a first pendant group comprising a quaternary ammonium component having the following formula: $-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$ wherein n is any integer from 1 to 18; R^1 is C(O)O or C(O)NH; R^2, R^3 and R^4 are each independently an optionally substituted alkyl, optionally substituted aryl, or R^2 and R^3 are taken together to form a ring and R^4 is H or absent; and X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and a second pendant group comprising an organosilane component.

In another aspect, there is provided a polymer having a plurality of pendant groups, wherein the pendant groups consists of: a first pendant group comprising a quaternary ammonium component having the following formula: $-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$ wherein n is any integer from 1 to 18; R^1 is C(O)O or C(O)NH; R^2 and R^3 are each independently an optionally substituted alkyl or optionally substituted aryl and R^4 is an optionally substituted C_{14} to C_{24} alkyl, or R^2 and R^3 are taken together to form a ring and R^4 is H or absent; and X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and a second pendant group comprising an organosilane component.

Advantageously, the polymer of the present disclosure is a more durable, stable and contact-active antimicrobial coating. In an embodiment, the polymer of the present disclosure comprises an antimicrobial quaternary ammonium compound moiety and an anchoring alkoxysilane functional group. Consisting of a permanent positive charge on the quaternary nitrogen, the polymer may attach itself via electrostatic attraction onto negatively charged microbial surfaces, such as bacteria. This attachment may impair the microbe's physiological functions by causing the microbe to lose electrical balance, destroying the cell membrane and ultimately leading to cell death. Additionally, the quaternary ammonium compound may insert its hydrophobic alkyl tail in to the cell cytoplasmic membrane where the hydrophobic interaction increases surface pressure and further disrupts cell membrane fluidity to cause cell death.

Further advantageously, the alkoxysilane functional group may be hydrolysed into reactive silanol that may cross-link with other silanol groups on substrate surfaces via condensation reactions. This may allow alkoxysilane-containing molecules to adhere covalently onto the surface via a siloxane bond. Siloxane bond cross-linking using the polymer of the present disclosure may be applied in a variety of materials including rubber, cotton or steel on top of silica-rich materials. Further advantageously, the polymer of the present disclosure is less sensitive to pH or inactivating enzymes as it is a synthetic molecule with a permanent charge.

Quaternary Aammonium Silanes (QAS), particularly dimethyloctadecyl[3-(trimethoxysilyl)propyl]ammonium chloride (DTPAC), has been extensively researched. DTPAC is a monomeric QAS that has been used in many coating applications. DTPAC coated medical devices have shown good *in-vitro* and *in-vivo* antimicrobial activities. DTPAC has the quaternary ammonium compound moiety and the alkoxylsilane moiety on the same pendant group.

Unlike DTPAC, the polymer of the present disclosure has the alkoxysilane and quaternary ammonium compound moiety separated on two separate pendant groups on the polymer. The polymer is synthesized by reacting two methacrylate-containing monomers, one containing the quaternary ammonium compound moiety and the other containing the alkoxysilane moiety, by free radical polymerization. Advantageously, since the two reactive moieties are on two separate pendant groups, it gives flexibility in polymer design. That is, the amount of alkoxysilane relative to the amount of quaternary ammonium compound moiety may be easily adjusted to optimise the property of the polymer.

Advantageously, the polymer of the present disclosure may contain, for example, 10 wt% of the anchoring alkoxysilane moiety whereas the antimicrobial quaternary ammonium component (QAC) may occupy the remaining 90 wt%. Further advantageously, the polymer of the present disclosure may have better coating efficacy, stability, contact-active antimicrobial activity, cytotoxicity and physical and functional durability compared to conventional antimicrobial QAS polymers such as DTPAC.

Further advantageously, the polymer of the present disclosure may be substantially free from any other pendant groups apart from the first pendant group comprising the quaternary ammonium component and the second pendant group comprising the organosilane component. That is, the polymer may substantially consist only of the first pendant group comprising the quaternary ammonium component and the second pendant group comprising the organosilane component. By substantially only having the first pendant group and the second pendant group, the polymer may have high antimicrobial performance, as the effectiveness of each pendant group is not compromised by the presence of additional pendant groups. That is, the maximum effectiveness of the properties of the first pendant group comprising the quaternary ammonium component (antimicrobial) and the second pendant group comprising the organosilane component (anchoring) may be achieved by not having additional pendant groups present in the polymer.

More advantageously, the polymer of the present disclosure may have durable and long-lasting antimicrobial properties that are superior to conventional antimicrobial agents such as DTPAC, even without the presence of additional pendant groups which may confer additional functionality to the polymer such as hydrophobicity.

There is provided a method for preparing a polymer as defined above, comprising the steps of contacting a first monomer with a second monomer in conditions suitable for polymerization, wherein a first monomer comprising a quaternary ammonium component having the following formula: $-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$ wherein

n is any integer from 1 to 18; R^1 is C(O)O or C(O)NH; R^2, R^3 and R^4 are each independently an optionally substituted alkyl, optionally substituted aryl, or R^2 and R^3 are taken together to form a ring and R^4 is H or absent; and X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and a second monomer comprising an organosilane component, provided that no other monomer is contacted with the first and second monomer in the polymer.

In another aspect, there is provided a method for preparing a polymer as defined above, comprising the steps of contacting a first monomer with a second monomer in conditions suitable for polymerization, wherein a first monomer comprising a quaternary ammonium component having the following formula: $-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$ wherein n is any integer from 1 to 18; R^1 is C(O)O or C(O)NH; R^2 and R^3 are each independently an optionally substituted alkyl or optionally substituted aryl and R^4 is an optionally substituted C_{14} to C_{24} alkyl, or R^2 and R^3 are taken together to form a ring and R^4 is H or absent; and X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and a second monomer comprising an organosilane component, provided that no other monomer is contacted with the first and second monomer in the polymer.

Advantageously, the polymer of the present disclosure may contain, for example, 90 wt% of the first monomer comprising a quaternary ammonium component, and 10 wt% of the second monomer comprising a organosilane component. Advantageously, this may allow for maximum antimicrobial efficacy by the quaternary ammonium component while maintaining sufficient anchoring of the polymer to a substrate via the organosilane component.

In another aspect, there is provided a polymer obtainable by the method as defined above.

In another aspect, there is provided an article comprising the polymer as defined above and a substrate comprising a surface.

Advantageously, the article comprising the polymer as defined above may also have all the same advantages conferred by the polymer as defined above.

In another aspect, there is provided a method for preparing the article as defined above, comprising the steps of: forming the polymer as defined above; and contacting the polymer with the surface of the substrate under conditions suitable to adhere the polymer to the surface of the substrate.

Advantageously, the use of a direct coating method using alkoxysilane may eliminate the need for elaborated coating procedures.

In an embodiment, the method may comprise the step of pre-treating the surface of the substrate prior to the contacting step, wherein the pre-treatment step comprises plasma cleaning. Advantageously, plasma cleaning may change the surface property, for example, by increasing the surface energy and roughness of the substrate, to facilitate adhesion of the polymer.

In another aspect, there is provided the use of the polymers as defined above as surface coatings.

Definitions

The following words and terms used herein shall have the meaning indicated:

The term “antimicrobial” refers to material that kills microorganisms or inhibits their growth.

The term “pendant group” refers to a group that is not part of the main backbone chain of the polymer.

Claims

1. A polymer having a plurality of pendant groups, wherein the pendant groups comprise:

   a first pendant group comprising a quaternary ammonium component having the following formula:

   $$-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$$

   wherein n is any integer from 1 to 18;

   R^1 is C(O)O or C(O)NH;

   R^2 and R^3 are each independently an optionally substituted alkyl or optionally substituted aryl and R^4 is an optionally substituted C_{14} to C_{24} alkyl,or wherein $R^2$and R^3 are taken together to form a ring and R^4 is H or absent; and

   X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and

   a second pendant group comprising an organosilane component,

   provided that the polymer is substantially free of any other pendant groups.

2. The polymer according to claim 1, wherein R^1 is C(O)O.

3. The polymer according to claim 1 or 2, wherein n is 2.

4. The polymer according to any one of the preceding claims, wherein R^2 and R^3 are each independently an optionally substituted C_1 to C_6 alkyl.

5. The polymer according to claim 4, wherein R^2 and R^3 are both methyl.

6. The polymer according to any one of the preceding claims, wherein the quaternary ammonium component has the following formula:

   $$-C(O)O-(CH_2)_2-[N^+(CH_3)_2(R^4)](X^-).$$

7. The polymer according to claim 6, R^4 is C_{16} H_{33}.

8. The polymer according to any one of the preceding claims, wherein the quaternary ammonium component has the following formula:

   $$-C(O)O-(CH_2)_2-N^+(CH_3)_2(C_{16}H_{33})(X^-).$$

9. The polymer according to claim 1 or 2, wherein n is 12 or 16.

10. The polymer according to claim 9, wherein $R^2$and R^3 are taken together to form a heterocyclic ring, and R^4 is H or absent.

11. The polymer according to claim 10, wherein the heterocyclic ring is pyridine.

12. The polymer according to any one of the preceding claims, wherein the organosilane component is organosilane or an organic silane ester.

13. The polymer according to claim 12, wherein the organosilane component has the following formula:

$$-R^5-(CH_2)_m-Si(-O-R^6)_3,$$

wherein m is any integer from 1 to 6;

R^5 is C(O)O or C(O)NH; and

R^6 is selected from the group consisting of H, an optionally substituted alkyl and a silane ester.

14. The polymer according to claim 13, wherein R^5 is C(O)O.

15. The polymer according to claim 13 or 14, wherein R^6 is an optionally substituted C_1 to C_5 alkyl.

16. The polymer according to claim 15, wherein R^6 is methyl.

17. The polymer according to any one of claims 13 to 16, wherein the organosilane component has any one of the following formulas:

$$-C(O)O-(CH_2)_3-Si(-O-CH_3)_3,$$

$$-C(O)O-(CH_2)_3-Si(-O-H)_3, \text{ or}$$

$$-C(O)O-(CH_2)_3-Si(-O-Si-R^7)_3,$$

wherein R^7 is an optionally substituted alkyl.

18. The polymer according to claim 17, wherein the organosilane component has the following formula:

19. $-C(O)O-(CH_2)_3-Si(-O-Si-CH_3)_3$.The polymer according to any one of the preceding claims, wherein the ratio of the organosilane component to the quaternary ammonium component is in the range of 1:2 to 1:5

20. A polymer having a plurality of pendant groups, wherein the pendant groups consists of:

a first pendant group comprising a quaternary ammonium component having the following formula:

$$-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$$

wherein n is any integer from 1 to 18;

R^1 is C(O)O or C(O)NH;

R^2 and R^3 are each independently an optionally substituted alkyl or optionally substituted aryl and R^4 is an optionally substituted C_{14} to C_{24} alkyl, or R^2 and R^3 are taken together to form a ring and R^4 is H or absent;

and X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and

a second pendant group comprising an organosilane component.

21. A method for preparing a polymer according to any one of claims 1 to 20, comprising the steps of contacting a first monomer with a second monomer in conditions suitable for polymerization, wherein

a first monomer comprising a quaternary ammonium component having the following formula:

$$-R^1-(CH_2)_n-[N^+(R^2)(R^3)(R^4)](X^-)$$

wherein n is any integer from 1 to 18;

R^1 is C(O)O or C(O)NH;

R^2 and R^3 are each independently an optionally substituted alkyl or optionally substituted aryl and R^4 is an optionally substituted C_{14} to C_{24} alkyl, or R^2 and R^3 are taken together to form a ring and R^4 is H or absent;

and

X is selected from the group consisting of Cl, Br, I and OSO_3CH_3; and

a second monomer comprising an organosilane component,

provided that no other monomer is contacted with the first and second monomer in the polymer.

22. The method according to claim 21, wherein the ratio of the first monomer comprising a quaternary ammonium component to the second monomer comprising an organosilane component is in the range of about 100:1 to 4:1 by weight.

23. The method according to claim 21 or 22, wherein the first monomer comprising the quaternary ammonium component and the second monomer comprising an organosilane component comprise a methacrylate group.

24. The method according to any one of claims 21 to 23, wherein the first monomer comprising the quaternary ammonium component is 2-(methacryloyloxy)ethyl]dimethyl hexadecyl ammonium bromide and the second monomer comprising the organosilane component is 3-trimethylsilylpropyl methacrylate.

25. A polymer obtainable by the method according to any one of claims 21 to 24.

26. An article comprising the polymer of any one of claims 1 to 20 and a substrate comprising a surface.

27. The article according to claim 26, wherein the polymer is adhered to the surface of the substrate.

28. The article according to claim 26 or 27, wherein the substrate comprises a material selected from the group consisting of non-siliceous ceramic material, siliceous material, metal, metal oxide, polymer and any mixture thereof.

29. The article according to any one of claims 26 to 28, wherein the substrate is in a form selected from the group consisting of film, sheet, tube, fiber, needle and any mixture thereof.

30. The article according to any one of claims 26 to 30, wherein the article is a medical device.

31. The article according to any one of claims 26 to 30, wherein article is a microneedle.

32. A method for preparing the article of any one of claims 26 to 31, comprising the steps of:

providing the polymer of any one of claims 1 to 20; and

contacting the polymer with the surface of the substrate under conditions suitable to adhere the polymer to the surface of the substrate.

33. The method of claim 32, wherein the polymer is solubilized in a solvent.

34. The method of claim 32 or 33, wherein the contacting step further comprises adding a catalyst.

35. The method of claim 34, wherein the catalyst is an acid.

36. The method of any of claims 34 to 35, comprising the step of pre-treating the surface of the substrate prior to the contacting step.

37. The method of claim 36, wherein the pre-treatment step comprises plasma cleaning.

38. The use of the polymer of any one of claims 1 to 20 as a surface coating.