the mechanism of action is through chemical interaction of the antimicrobials with the microbes, which may lead to drug resistant microbes.

There is therefore a need to provide a substrate that overcomes, or at least ameliorates, one or more of the disadvantages described above. Specifically, there is a need to provide a material that is biocompatible, inexpensive and does not give rise to drug resistance in microbes.

Summary

There is provided a substrate coated with a layered double hydroxide having the following structure (A):

$$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_{2}]^{x+}[(X^{n-})_{x/n}.yH_{2}O]^{x-} \quad (A)$$

wherein

M^{2+} is a divalent cation;

N^{3+} is a trivalent cation;

x is in the range of 1/6 to 1/2;

y is in the range of 0.5 to 4;

X^{n-} is an anion; and

n is an integer selected from 1, 2 or 3;

wherein the layered double hydroxide is surface modified with a group 10 element on the Periodic Table of Elements or a compound selected from the group consisting of: a fatty acid, a polymer, and an amino acid.

Advantageously, the substrate coated with the layered double hydroxide (LDH) as disclosed herein may act as an antimicrobial even in the absence of antimicrobial chemicals. More advantageously, the layered double hydroxide (LDH) may be surface modified with a non-antimicrobial group 10 element on the Periodic Table of Elements or a non-antimicrobial compound selected from the group consisting of: a fatty acid, a polymer, and an amino acid to confer antimicrobial properties to a surface.

Advantageously, the surface-modification of the LDH with a non-antimicrobial compound may alter the hydrophilicity of the LDH, which may in turn confer the antimicrobial properties to the LDH. Advantageously, this may overcome the limitations of conventional antimicrobial chemicals of developing drug resistance.

Further advantageously, non-surface-modified vertically aligned LDH (V-LDH) array may have very weak antimicrobial property. However, the surface modified V-LDH array may

advantageously exhibit excellent antimicrobial properties. Further advantageously, LDH may have excellent biocompatibility.

In one aspect, there is provided a substrate coated with a layered double hydroxide having the following structure (A):

$$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_{2}]^{x+}[(X^{n-})_{x/n}.yH_{2}O]^{x-} \quad (A)$$

wherein

M^{2+} is a divalent cation;

N^{3+} is a trivalent cation;

x is in the range of 1/6 to 1/2;

y is in the range of 0.5 to 4;

X^{n-} is an anion; and

n is an integer selected from 1, 2 or 3;

wherein the layered double hydroxide is surface modified with an amino acid.

There is provided a method of preparing a substrate coated with a surface-modified layered double hydroxide, the method comprising the steps of:

providing a substrate coated with a layered double hydroxide having the following structure (A):

$$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_{2}]^{x+}[(X^{n-})_{x/n}.yH_{2}O]^{x-} \quad (A)$$

wherein

M^{2+} is a divalent cation;

N^{3+} is a trivalent cation;

x is in the range of 1/6 to 1/2;

y is in the range of 0.5 to 4;

X^{n-} is an anion; and

n is an integer selected from 1, 2 or 3; and

contacting the substrate coated with a layered double hydroxide with a group 10 element on the Periodic Table of Elements or a compound selected from the group consisting of: a fatty acid, a polymer, and an amino acid.

In an example, the substrate coated with the layered double hydroxide may be prepared by contacting a substrate with a compound having a formula $M'(X')_2.zH_2O$ and a compound having a formula $N'(X')_3.zH_2O$ in the presence of a base,

wherein M' is a divalent cation;

N' is a trivalent cation;

z is independently in the range of 1 to 12;

X' is independently an anion; and

heating the substrate.

Advantageously, the surface modified layered double hydroxide may be prepared by simply combining two inexpensive metal salts with a base such as urea and the chemicals used for surface modification may be inexpensive and readily available. Furthermore, the method is scalable.

More advantageously, the double layered hydroxide may be prepared in water, without the need for organic solvents, which is environmentally friendly.

Further advantageously, the modified layered double hydroxide may be coated on a variety of substrates such as glass, plastics, metals, ceramics, silicone and any mixture thereof. This makes the process versatile, with the ability to be adapted to a variety of applications. More advantageously, the coating may adhere strongly to the substrate.

In another aspect, there is provided a method of preparing a substrate coated with a surface-modified layered double hydroxide, the method comprising the steps of:

providing a substrate coated with a layered double hydroxide having the following structure (A):

$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_2]^{x+}[(X^{n-})_{x/n}.yH_2O]^{x-}$ (A)

wherein

M^{2+} is a divalent cation;

N^{3+} is a trivalent cation;

x is in the range of 1/6 to 1/2;

y is in the range of 0.5 to 4;

X^{n-} is an anion; and

n is an integer selected from 1, 2 or 3; and

contacting the substrate coated with a layered double hydroxide with an amino acid.

There is provided the use of a layered double hydroxide as an antimicrobial, the layered double hydroxide having the following structure (A):

$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_2]^{x+}[(X^{n-})_{x/n}.yH_2O]^{x-}$ (A)

wherein

M^{2+} is a divalent cation;

N^{3+} is a trivalent cation;

x is in the range of 1/6 to 1/2;

y is in the range of 0.5 to 4;

X^{n-} is an anion; and

n is an integer selected from 1,2 or 3;

wherein the layered double hydroxide is surface modified with a group 10 element on the Periodic Table of Elements or a compound selected from the group consisting of: a fatty acid, a polymer, and an amino acid.

Advantageously, surface modification may alter the hydrophilicity of the layered double hydroxide, thereby resulting in a reduction in microbial count on the surface. Advantageously, the surface modified layered double hydroxide may achieve up to 7 log reduction of bacteria. Further advantageously, surface modified layered double hydroxide may have good blood clearance and may be well absorbed by the human body, making them extremely biocompatible.

In another aspect, there is provided use of a layered double hydroxide as an antimicrobial, the layered double hydroxide having the following structure (A):

$$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_2]^{x+}[(X^{n-})_{x/n}.yH_2O]^{x-} \quad (A)$$

wherein

M^{2+} is a divalent cation;

N^{3+} is a trivalent cation;

x is in the range of 1/6 to 1/2;

y is in the range of 0.5 to 4;

X^{n-} is an anion; and

n is an integer selected from 1, 2 or 3;

wherein the layered double hydroxide is surface modified with an amino acid.

In another aspect, there is provided the use of a calcined layered double hydroxide as an antimicrobial, the layered double hydroxide having the following structure (A):

$$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_2]^{x+}[(X^{n-})_{x/n}.yH_2O]^{x-} \quad (A)$$

wherein

M^{2+} is a divalent cation;

N^{3+} is a trivalent cation;

x is in the range of 1/6 to 1/2;

y is in the range of 0.5 to 4;

Claims

1. Use of a calcined layered double hydroxide as an antimicrobial, the layered double hydroxide having the following structure (A):

   $[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_2]^{x+}[(X^{n-})_{x/n}.yH_2O]^{x-}$ (A)

   wherein

   M^{2+} is a divalent cation;

   N^{3+} is a trivalent cation;

   x is in the range of 1/6 to 1/2;

   y is in the range of 0.5 to 4;

   X^{n-} is an anion; and

   n is an integer selected from 1, 2 or 3.

2. A substrate coated with a layered double hydroxide having the following structure (A):

   $[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_2]^{x+}[(X^{n-})_{x/n}.yH_2O]^{x-}$ (A)

   wherein

   M^{2+} is a divalent cation;

   N^{3+} is a trivalent cation;

   x is in the range of 1/6 to 1/2;

   y is in the range of 0.5 to 4;

   X^{n-} is an anion; and

   n is an integer selected from 1, 2 or 3;

   wherein the layered double hydroxide is surface modified with an amino acid.

3. The substrate according to claim 2, wherein the layered double hydroxide is calcined.

4. The substrate according to claim 2 or 3, wherein the divalent cation is selected from a group 2, group 7, group 8, group 9, group 10, group 11 or group 12 element on the Periodic Table of Elements or, wherein the divalent cation is selected from the group consisting of Mg^{2+}, Zn^{2+}, Cu^{2+}, Ni^{2+} and Co^{2+}.

5. The substrate according to any one of claims 2 to 4, wherein the trivalent cation is selected from a group 6, group 8, or group 13 element on the Periodic Table of Elements or, wherein the trivalent cation is selected from the group consisting of Al^{3+}, Fe^{3+} and Cr^{3+}.

6. The substrate according to any one of claims 2 to 5, wherein the stoichiometric M^{2+}:N^{3+} ratio is in the range of 1:1 to 5:1.

7. The substrate according to any one of claims 2 to 6, wherein X^{n-} is NO_3^- or Cl^- and n is 1, or X^{n-} is SO_4^{2-} and n is 2.

8. The substrate according to any one of claims 2 to 7, wherein the layered double hydroxide:
   i) is vertically aligned;
   ii) has a hexagonal shape;
   iii) has an average thickness in the range of 50 nm to 175 nm; and/or
   iv) has an average spacing between each piece of adjacent LDH in the range of 300 nm to 550 nm.

9. The substrate according to any one of claims 3 to 8, wherein the calcined layered double hydroxide has an average thickness in the range of 50 nm to 100 nm.

10. The substrate according to any one of claims 2 to 9, wherein the amino acid is an amino acid having a charged side chain, or the amino acid is L-glutamic acid or L-arginine.

11. The substrate according to any one of claims 2 to 10, wherein the substrate is selected from the group consisting of glass, plastic, metal or alloy, ceramic and any mixture thereof.

12. A method of preparing a substrate coated with a surface-modified layered double hydroxide, the method comprising the steps of:

    providing a substrate coated with a layered double hydroxide having the following structure (A):

    $$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^-)_2]^{x+}[(X^{n-})_{x/n}.yH_2O]^{x-} \quad (A)$$

    wherein

    M^{2+} is a divalent cation;

    N^{3+} is a trivalent cation;

    x is in the range of 1/6 to 1/2;

    y is in the range of 0.5 to 4;

    X^{n-} is an anion; and

    n is an integer selected from 1, 2 or 3; and

contacting the substrate coated with a layered double hydroxide with an amino acid.

13. The method according to claim 12, further comprising the step of calcining the layered double hydroxide before contacting the substrate with the amino acid.

14. The method according to claim 13, wherein the calcining step is performed in air at a temperature in the range of 400 ^{o}C to 500 ^{o}C for a duration in the range of 15 hours to 20 hours.

15. The method according to any one of claims 12 to 14, wherein the substrate coated with the layered double hydroxide is prepared by contacting a substrate with a compound having a formula $M'(X')_2.zH_2O$ and a compound having a formula $N'(X')_3.zH_2O$ in the presence of urea base,

wherein M' is a divalent cation;

N' is a trivalent cation;

z is independently in the range of 1 to 12;

X' is independently an anion; and

heating the substrate.

16. The method according to any one of claims 12 to 15, wherein M':N' is in the ratio of 2:1, and wherein $M'(X')_2.yH_2O$ is $Mg(NO_3)_2.6H_2O$ and $N'(X')_3.yH_2O$ is $Al(NO_3)_3.9H_2O$.

17. The method according to any one of claims 12 to 16, wherein the heating step is performed at a temperature in the range of 80 ^{o}C to 110 ^{o}C for a duration in the range of 40 hours to 60 hours.

18. Use of a layered double hydroxide as an antimicrobial, the layered double hydroxide having the following structure (A):

$$[M^{2+}_{(1-x)}N^{3+}_{x}(HO^{-})_2]^{x+}[(X^{n-})_{x/n}.yH_2O]^{x-} \quad (A)$$

wherein

M^{2+} is a divalent cation;

N^{3+} is a trivalent cation;

x is in the range of 1/6 to 1/2;

y is in the range of 0.5 to 4;

X^{n-} is an anion; and

n is an integer selected from 1, 2 or 3;

wherein the layered double hydroxide is surface modified with an amino acid.

19. The use according to claim 18, wherein the layered double hydroxide is calcined.

20. The use according to claim 18 or 19, wherein the antimicrobial inhibits the growth of a microorganism, and the microorganism is selected from the group consisting of *E. coli*, *S. aureus*, Methicillin-resistant *S. aureus* and *C. albicans*.