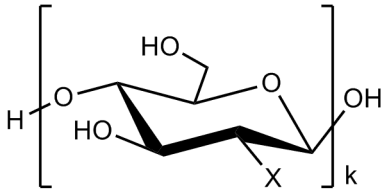
CLAIMS

1. A hybrid nanomaterial comprising graphene oxide nanomaterial covalently conjugated to cationic quaternized chitosan, wherein the cationic quaternized chitosan prior to the conjugation is represented by formula (I)



(I)

wherein

X, at each occurrence, is independently selected from –NH-C(O)-CH_3, -N(R^1)(R^2) and -N^+(R^3)(R^4)(R^5), provided that at least one X is -N^+(R^3)(R^4)(R^5),

R^1 and R^2 are independently selected from H and C_{1-18} alkyl,

R^3, R^4 and R^5 are each independently C_{1-18} alkyl, and

k is an integer from 3 to 3000;

wherein the graphene oxide nanomaterial is covalently conjugated to the cationic quaternized chitosan at an occurrence of X, wherein the occurrence of X is –NH_2.

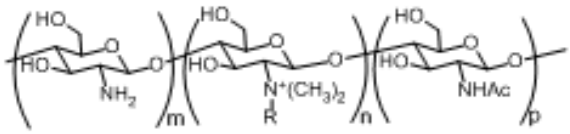
2. The hybrid nanomaterial according to claim 1, wherein R^1 and R^2 are selected from H and C_{1-18} alkyl; and R^3, R^4, and R^5 are each independently C_{1-10} alkyl.

3. The hybrid nanomaterial according to claim 2, wherein R^3 and R^4 are methyl and R^5 is C_{1-10} alkyl.

4. The hybrid nanomaterial according to claim 1, wherein the ratio of monomers with X = -N(R^1)(R^2) and X= -N^+(R^3)(R^4)(R^5) to monomers with X = –NH-C(O)-CH_3 is in the range of 2:1 to 5:1.

5. The hybrid nanomaterial according to claim 4, wherein the ratio of monomers with X = -N(R^1)(R^2) to monomers with X= -N^+(R^3)(R^4)(R^5) is in the range of 1:4 to 4:1.

6. The hybrid nanomaterial according to claim 1, wherein the cationic quaternized chitosan comprises dimethyldecylammonium chitosan having general formula (II)



(II)

wherein

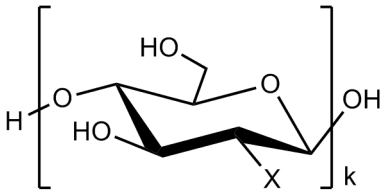
R is selected from the group consisting of $–CH_2(CH_2)_8CH_3$ and $–CH_3$, wherein at least one occurrence of R is $–CH_2(CH_2)_8CH_3$; and

ratio of m:n:p is 3:5:2.

7. The hybrid nanomaterial according to claim 1, wherein the weight ratio of graphene oxide to cationic quaternized chitosan in the hybrid nanomaterial is in the range of about 1:2 to about 1:3.

8. The hybrid nanomaterial according to claim 1, wherein the cationic quaternized chitosan is covalently bonded to the graphene oxide via an amide bond.

9. An antimicrobial composition comprising a liquid and a hybrid nanomaterial comprising graphene oxide nanomaterial covalently conjugated to cationic quaternized chitosan, wherein the cationic quaternized chitosan prior to the conjugation is represented by formula (I)



(I)

wherein

X, at each occurrence, is independently selected from $–NH\text{-}C(O)\text{-}CH_3$, $-N(R^1)(R^2)$ and $-N^+(R^3)(R^4)(R^5)$, provided that at least one X is $-N^+(R^3)(R^4)(R^5)$,

R^1 and R^2 are independently selected from H and $C_{1\text{-}18}$ alkyl,

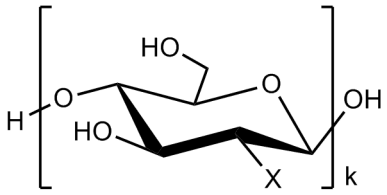
R^3, R^4 and R^5 are each independently C_{1-18} alkyl, and

k is an integer from 3 to 3000; and

wherein the graphene oxide nanomaterial is covalently conjugated to the cationic quaternized chitosan at an occurrence of X, wherein the occurrence of X is $–NH_2$.

10. The antimicrobial composition according to claim 9, wherein concentration of the hybrid nanomaterial ranges from about 20 μg mL^{-1} to about 3000 μg mL^{-1} of the composition.

11. A method of preparing a hybrid nanomaterial comprising graphene oxide nanomaterial covalently conjugated to cationic quaternized chitosan, wherein the cationic quaternized chitosan prior to the conjugation is represented by formula (I)



(I)

wherein

X, at each occurrence, is independently selected from –NH-C(O)-CH_3, -N(R^1)(R^2) and -N^+(R^3)(R^4)(R^5), provided that at least one X is -N^+(R^3)(R^4)(R^5),

R^1 and R^2 are independently selected from H and C_{1-18} alkyl,

R^3, R^4 and R^5 are each independently C_{1-18} alkyl, and

k is an integer from 3 to 3000; and

wherein the graphene oxide nanomaterial is covalently conjugated to the cationic quaternized chitosan at an occurrence of X, wherein the occurrence of X is $–NH_2$, the method comprising reacting cationic quaternized chitosan of formula (I) with graphene oxide in the presence of a coupling reagent to covalently bond the cationic quaternized chitosan to the graphene oxide.

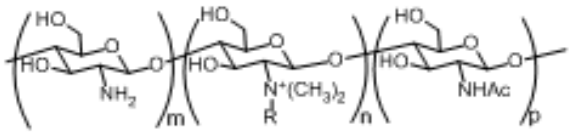
12. The method according to claim 11, wherein R^1 and R^2 are selected from H and C_{1-18} alkyl; and R^3, R^4, and R^5 are each independently C_{1-10} alkyl.

13. The method according to claim 12, wherein R^3 and R^4 are methyl and R^5 is C_{1-10} alkyl.

14. The method according to claim 11, wherein the ratio of monomers with X = -$N(R^1)(R^2)$ and X= -$N^+(R^3)(R^4)(R^5)$ to monomers with X = –NH-C(O)-CH_3 is in the range of 2:1 to 5:1.

15. The method according to claim 14, wherein the ratio of monomers with X = -$N(R^1)(R^2)$ to monomers with X= -$N^+(R^3)(R^4)(R^5)$ is in the range of 1:4 to 4:1.

16. The method according to claim 11, wherein the cationic quaternized chitosan comprises dimethyldecylammonium chitosan having general formula (II)



(II)

wherein

R is selected from the group consisting of $–CH_2(CH_2)_8CH_3$ and $–CH_3$, wherein at least one occurrence of R is $–CH_2(CH_2)_8CH_3$; and

ratio of m:n:p is 3:5:2.

17. The method according to claim 11, wherein the coupling reagent comprises 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide.

18. The method according to claim 17, wherein the coupling reagent further comprises N-hydroxysuccinimide.

19. The method according to claim 11, wherein the cationic quaternized chitosan is covalently bonded to the graphene oxide via an amide bond.

20. The method according to claim 11, wherein the weight ratio of graphene oxide to the cationic quaternized chitosan is in the range of about 1:1 to about 1:10.