

CLAIMS:

1. An article comprising a substrate and an anti-microbial coating, wherein the anti-microbial coating comprises at least one solvent-free black phosphorus flake.
2. An article according to claim 1, wherein the at least one black phosphorus flake generates reactive oxygen species (ROS) that are active towards at least some types of micro-organisms.
3. An article according to claim 1 or 2, wherein the anti-microbial coating prevents the growth of, or kills, one or more micro-organisms selected from the group consisting of bacterial cells and fungal cells or spores.
4. An article according to any one of claims 1 to 3, wherein the anti-microbial coating has a density that falls within a range of from about 0.1 ng of black phosphorus per μm^2 of substrate to about 1.0 ng of black phosphorus per μm^2 of substrate.
5. An article according to any one of claims 1 to 4, wherein the anti-microbial coating has a density that falls within a range of from about 0.2 ng of black phosphorus per μm^2 of substrate to about 0.6 ng of black phosphorus per μm^2 of substrate.
6. An article according to any one of claims 1 to 4, wherein the anti-microbial coating has a density of about 0.4 ng of black phosphorus per μm^2 of substrate.
7. An article according to any one of claims 1 to 6, wherein the anti-microbial coating prevents the growth of, or kills, one or more bacterial species selected from the group consisting of: *Escherichia coli*, *Pseudomonas aeruginosa*, methicillin-resistant *staphylococcus aureus* (MRSA) (resistive species), *Salmonella typhimurium*, or *Bacillus cereus*.
8. An article according to any one of claims 1 to 6, wherein the anti-microbial coating prevents the growth of, or kills, one or more fungal species selected from the group consisting of: *Candida albicans*, *Candida auris* (*C. auris*), sensitive *Cryptococcus neoformans*, fluconazole-resistant *Cryptococcus neoformans*, or Ampicillin-resistant *Cryptococcus neoformans*.

9. An article according to any one of claims 1 to 6, wherein the anti-microbial coating kills at least about 90% of microorganisms within a period of 120 minutes under ambient conditions, wherein the microorganism is selected from the group consisting of: methicillin-resistant *Staphylococcus aureus*, or *Escherichia coli*, or *Pseudomonas aeruginosa*, or *Salmonella typhimurium*, or *Bacillus cereus*, or *Candida albicans*, or *Candida auris*, or Sensitive *Cryptococcus neoformans*, or fluconazole-resistant *Cryptococcus neoformans*, or Ampicillin-resistant *Cryptococcus neoformans*.
10. An article according to any one of claims 1 to 9, wherein the at least one black phosphorus flake has an average thickness that falls within a range of from about 10 nm to about 120 nm.
11. An article according to any one of claims 1 to 9, wherein the at least one black phosphorus flake has an average thickness that falls within a range of from about 15 nm to about 90 nm.
12. An article according to any one of claims 1 to 11, wherein the at least one black phosphorus flake has an average lateral dimension that falls within a range of from about 500 nm to about 5 μm .
13. An article according to any one of claims 1 to 12, wherein the at least one black phosphorus flake is produced from a black phosphorus crystal by mechanical exfoliation.
14. An article according to claim 13, wherein the mechanical exfoliation is conducted in a solvent-free environment.
15. An article according to any one of claims 1 to 14, wherein the at least one black phosphorus flake is physically adsorbed on to a surface of the substrate.
16. An article according to any one of claims 1 to 14, wherein the at least one black phosphorus flake is deposited onto a surface of the substrate by contacting the substrate surface with an applicator having at least one black phosphorus flake in contact with a surface thereof.
17. An article according to any one of claims 2 to 16, wherein the reactive oxygen species (ROS) are generated when the black phosphorus flake is exposed to atmospheric oxygen.

18. An article according to any one of claims 2 to 17, wherein the reactive oxygen species (ROS) are generated under ambient conditions.
19. An article according to any one of claims 2 to 18, wherein the reactive oxygen species are selected from the group consisting of a singlet oxygen radical ($^1\text{O}_2$), a hydroxy radical ($\text{OH}\cdot$), a superoxide radical ($\text{O}_2^{\cdot-}$) and hydrogen peroxide (H_2O_2).
20. An article according to any one of claims 2 to 19, wherein the reactive oxygen species (ROS) are not substantially cytotoxic towards mammalian cells.
21. An article according to any one of claims 1 to 20, wherein the article is an implant, a medical instrument, a bioscaffold, or a woven or non-woven textile.
22. An article according to any one of claims 1 to 21, wherein the substrate is selected from the group consisting of: a metal, an alloy, a polymer, a textile, a glass, a ceramic, or any combination thereof.
23. An article according to claim 22, wherein the metal is selected from the group consisting of titanium, gold, stainless steel, aluminium, copper, or any combination thereof.
24. An article according to any one of claims 1 to 23, wherein the at least one black phosphorous flake is adhered to the substrate.
25. A method of producing an article having an anti-microbial coating, comprising:
 - providing a substrate;
 - depositing at least one black phosphorus flake onto a surface of the substrate in the absence of solvent.
26. A method according to claim 25, wherein the at least one black phosphorus flake generates reactive oxygen species (ROS) that are active towards at least some types of micro-organisms.
27. A method according to claim 25 or 26, wherein the anti-microbial coating prevents the growth of, or kills, micro-organisms selected from the group consisting of bacterial cells, and fungal cells or spores.
28. A method according to any one of claims 25 to 27, wherein the anti-microbial coating has a density that falls within a range of from about 0.1 ng of black

phosphorus per μm^2 of substrate to about 1.0 ng of black phosphorus per μm^2 of substrate.

29. A method according to any one of claims 25 to 28, wherein the anti-microbial coating has a density that falls within a range of from about 0.2 ng of black phosphorus per μm^2 of substrate to about 0.6 ng of black phosphorus per μm^2 of substrate.
30. A method according to any one of claims 25 to 28, wherein the anti-microbial coating has a density that falls within a range of from about 0.4 ng of black phosphorus per μm^2 of substrate.
31. A method according to any one of claims 25 to 30, wherein the anti-microbial coating prevents the growth of, or kills, one or more bacterial species selected from the group consisting of: *Escherichia coli*, *Pseudomonas aeruginosa*, methicillin-resistant *staphylococcus aureus* (MRSA) (resistive species), *Salmonella typhimurium*, or *Bacillus cereus*.
32. A method according to any one of claims 25 to 30, wherein the anti-microbial coating prevents the growth of, or kills, one or more fungal species selected from the group consisting of: *Candida albicans*, sensitive *Cryptococcus neoformans*, fluconazole-resistant *Cryptococcus neoformans*, or Ampicillin-resistant *Cryptococcus neoformans*.
33. A method according to any one of claims 25 to 30, wherein the anti-microbial coating kills at least about 90% of microorganisms within a period of 120 minutes under ambient conditions, wherein the microorganism is selected from the group consisting of: methicillin-resistant *Staphylococcus aureus*, or *Escherichia coli*, or *Pseudomonas aeruginosa*, or *Salmonella typhimurium*, or *Bacillus cereus*, or *Candida albicans*, or *Candida auris*, or Sensitive *Cryptococcus neoformans*, or fluconazole-resistant *Cryptococcus neoformans*, or Ampicillin-resistant *Cryptococcus neoformans*.
34. A method according to any one of claims 25 to 33, wherein the at least one black phosphorus flake has an average thickness that falls within a range of from about 10 nm to about 120 nm.

35. A method according to any one of claims 25 to 33, wherein the at least one black phosphorus flake has an average thickness that falls within a range of from about 15 nm to about 90 nm.
36. A method according to any one of claims 25 to 35, wherein the at least one black phosphorus flake has an average lateral dimension that falls within a range of from about 500 nm to about 5 μm .
37. A method according to any one of claims 25 to 36, wherein the at least one black phosphorus flake is produced from a black phosphorus crystal by mechanical exfoliation.
38. A method according to claim 37, wherein the mechanical exfoliation is conducted in a solvent-free environment.
39. A method according to any one of claims 25 to 38, wherein the at least one black phosphorus flake is physically adsorbed on to a surface of the substrate.
40. A method according to any one of claims 25 to 38, wherein the at least one black phosphorus flake is deposited onto a surface of the substrate by contacting the substrate surface with an applicator having at least one black phosphorus flake in contact with a surface thereof.
41. A method according to any one of claims 26 to 40, wherein the reactive oxygen species (ROS) are generated when the black phosphorus flake is exposed to atmospheric oxygen.
42. A method according to any one of claims 26 to 41, wherein the reactive oxygen species (ROS) are generated under ambient conditions.
43. A method according to any one of claims 26 to 42, wherein the reactive oxygen species are selected from the group consisting of a singlet oxygen radical ($^1\text{O}_2$), a hydroxy radical ($\text{OH}\cdot$), a superoxide radical ($\text{O}_2^{\cdot-}$) and hydrogen peroxide (H_2O_2).
44. A method according to any one of claims 26 to 43, wherein the reactive oxygen species (ROS) are not substantially cytotoxic towards mammalian cells.
45. A method according to any one of claims 25 to 44, wherein the at least one black phosphorous flake is adhered to the substrate.

46. A method according to any one of claims 25 to 45, wherein the substrate is selected from the group consisting of: a metal, an alloy, a polymer, a textile, a glass, a ceramic, or any combination thereof.
47. A method according to claim 46, wherein the metal is selected from the group consisting of titanium, gold, stainless steel, aluminium, copper, or any combination thereof.
48. A method according to any one of claims 25 to 47, wherein the substrate is produced from a medical grade metal or alloy.
49. A method according to any one of claims 25 to 47, wherein the substrate is a surgical implant.
50. A method according to any one of claims 25 to 47, wherein the substrate is a bioscaffold.
51. A method according to any one of claims 25 to 47, wherein the substrate is a woven or non-woven textile.
52. An article produced according to the method of any one of claims 25 to 51.
53. Use of at least one solvent-free black phosphorus flake in the manufacture of an anti-microbial coating for a substrate.
54. A solvent-free black phosphorous flake for use in an anti-microbial coating on a substrate.
55. A method of producing at least one solvent-free black phosphorus flake with anti-microbial activity, comprising:
 - contacting a black phosphorus crystal with an applicator having an adhesive surface to cause the applicator to adhere to a surface of the black phosphorus crystal; and
 - removing the applicator from the surface of the black phosphorous crystal, thereby mechanically exfoliating at least one black phosphorous flake from the black phosphorous crystal.
56. An anti-microbial coating, comprising:
 - at least one black phosphorus flake produced in the absence of solvent.

57. An anti-microbial coating according to claim 56, wherein the at least one black phosphorus flake generates reactive oxygen species (ROS) that are active towards at least some types of micro-organisms.

An article comprising a substrate and an anti-microbial coating according to claim 56 or 57, wherein the at least one black phosphorus flake is deposited on a surface of the substrate in the absence of solvent.