

Figure 1: Schematic representation of the various points discussed in this review paper

Table I: Type of surface depending on the CA

|  |  |
| --- | --- |
| **Type of surface** | **Contact angle (CA)** |
| Superhydrophobic | CA>150° |
| Hydrophobic | 150°>CA>90° |
| Hydrophilic | 90°>CA>10° |
| Superhydrophilic | CA<10° |



Figure 2: Models used to measure the contact angle of the surface. a) Young, b) Wenzel and c) Cassie-Baxter model

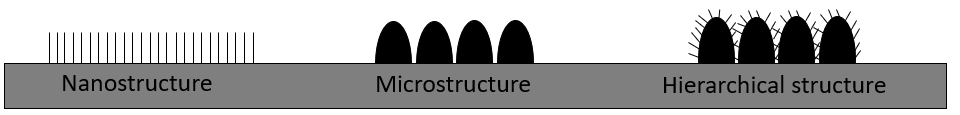


Figure 3 Different levels of structures, from nanostructures to hierarchical structures.

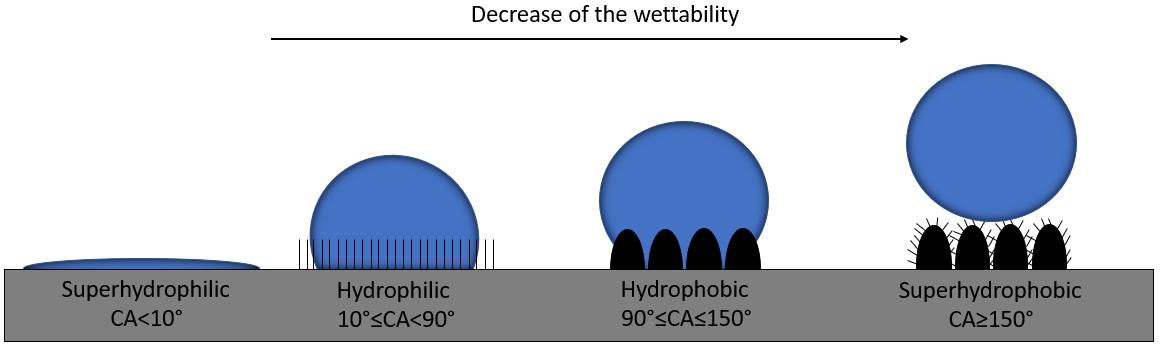


Figure 4 Different surface structures, starting smooth surface (left), nanostructure, microstructure and hierarchical structure (right). Adapted from 21



Figure 5: Functionalities of some of the nature inspired surfaces and some of their most studied examples.

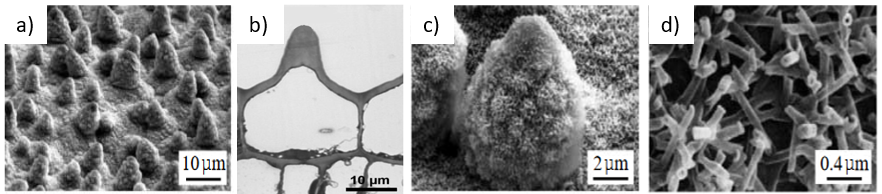


Figure 6 a) Microstructure of the lotus leaf. Adapted from33 b) Cross section of the micropapillae. Adapted from 34 c) Micropapillae covered with epicuticular waxes. Adapted from 33 c) branch like nanostructures. Adapted from 33

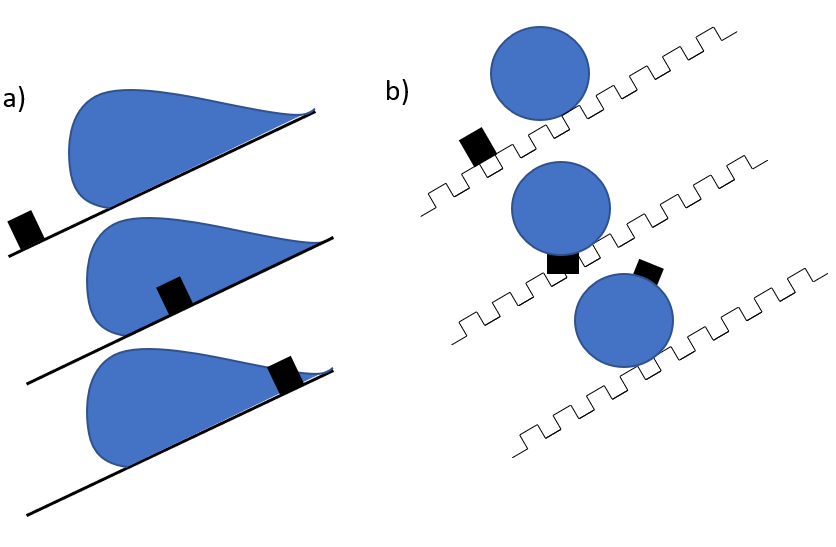


Figure 7 Schematic illustration of the lotus leaf self-cleaning effect a) ideal smooth surfaces b) rough surfaces (black mark indicates a roll off point)

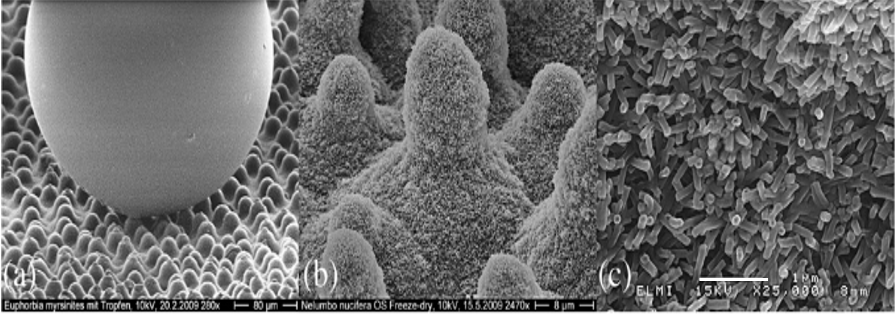


Figure 8: a) SEM image of the taro leaf with a water droplet showing the superhydrophobic properties b) taro leaf bump-like microstructure and c) Bumps covered by epicuticular waxes. Adapted from 38. Scale bars are a) 80 µm b) 8 µm c) 1 µm.

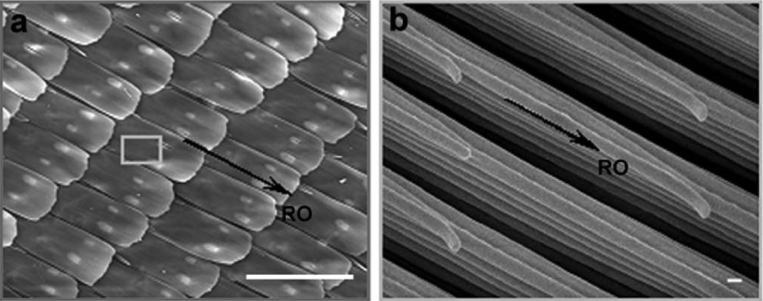


Figure 9 a) Butterfly wing scales and b) nanostripes. Adapted from 44.

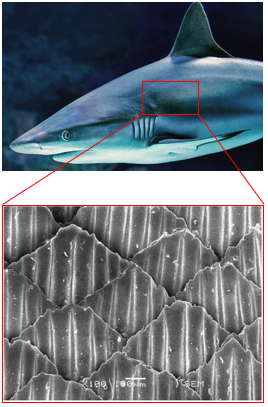


Figure 10 Shark skin riblet based microstructure.

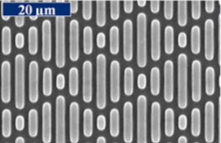


Figure 11 Scanning electron micrograph of the top view Sharklet AFTM microstructure. Adapted from46.

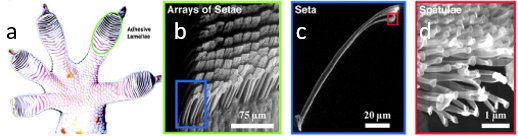


Figure 12 a) Gecko foot. b) Group of setae c) a single seta and d) Group of spatulae Adapted from51.

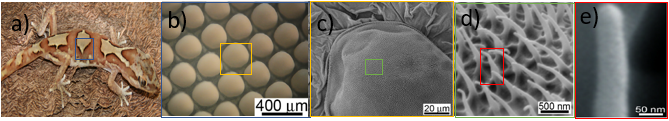


Figure 13: a) Lucasium steindachneri gecko b) Optical image of the abdominal part of gecko c) Topographical SEM image of the scales. d) Group of spinules in the top of the scales. e) magnification of the spinules at the nanometer scale. Adapted from 9.

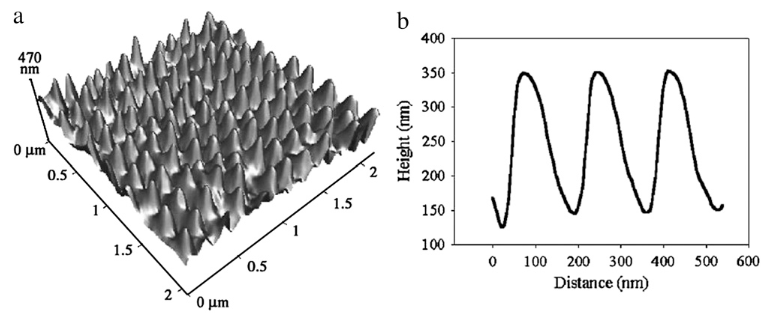


Figure 14: a) AFM three-dimensional image of cicada wing and b) corresponding height and width profile. Adapted from 55.

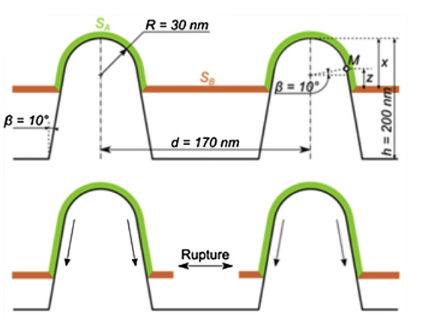


Figure 15: Model of cicada wing and bacteria explaining rupture of bacteria. Adapted from 57.

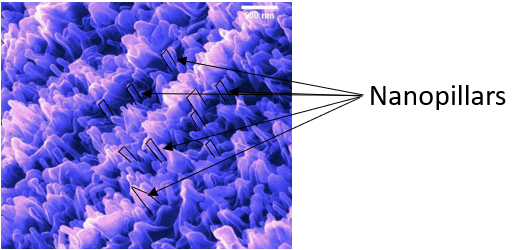


Figure 16: Pillar like nanostructure of the dragonfly wings. Adapted from 13

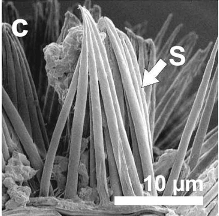
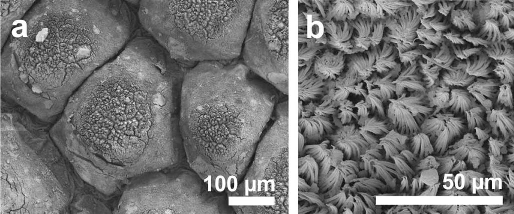


Figure 17 Scanning electron micrographs of the chameleo calyptratus a) Microstructure of the chameleon with a scale-like microstructure. b) Setae covering the scale-like microstructure. c) Cross-section of the scale with the setae (S). Adapted from 63.

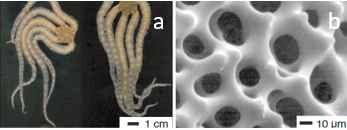


Figure 18 a) Brittle star image and b) SEM image of its microstructure. Adapted from 68.

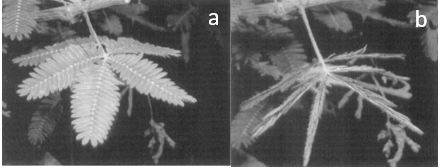


Figure 19 Leaves of the *Mimosa pudica* a) open and b) close. Adapted from 70.

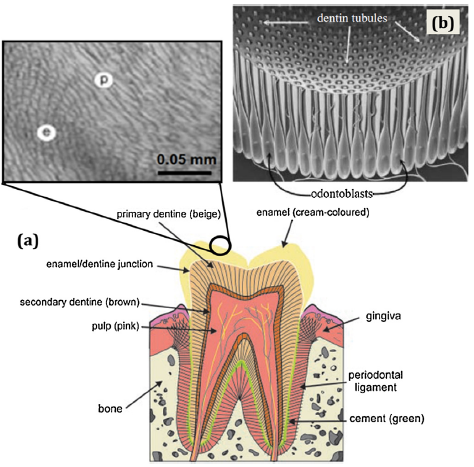


Figure 20 a) The main structure of human teeth, b) Tubular structure of the dentin. Adapted from 22.

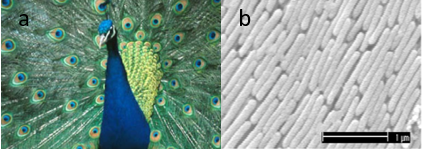


Figure 21 a) Peacock with its feathers. Adapted from 81. b) longitudinal cross section of the barbs. Adapted from 82.

Table II Natural dimensions of most promising antibacterial surfaces based on the literature.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Natural surface** | **Wettability (°)** | **Microstructure** | | | **Nanostructure** | | | | **Reference** | |
| **Height (µm)** | **Base (µm)** | **Spacing (µm)** | **Height (nm)** | **Base (nm)** | **Spacing (nm)** |  | |
| Lotus leaf | >150 | - | Ø5-Ø9 | - | - | Ø120 | - | 22 | |
| Lotus leaf | 164 | 13 | Ø10 | - | 780 | Ø400 | - | 10 | |
| Lotus leaf | >150 | 10.4±0.8 | 8±2.4 | 19.5±12.5 | 530±150 | Ø100±30 | - | 84 | |
| Shark skin | - | 200-500 | 100-300 | 100-300 | - | | | | 35 | |
| Shark skin | - | 8 | - | 60 | - | | | | 85 | |
| Gecko dorsal | 151-155 | 50 | Ø100-Ø190 | 50 | Up to 4000 | - | - | 9 | |
| Gecko dorsal | - | - | 160 | 210 | 3000 | Ø350-Ø400 | 500 | 86 | |
| Cicada wing | 144±7 | Not hierarchical | | | 200 | Ø170 | 200 | 55 | |
| Cicada wing | - | Not hierarchical | | | 300 | Ø90 | 170 | 87 | |
| Cicada wing | 146 | Not hierarchical | | | 146-157 | Ø82-148 | 44-177 | 36 | |
| Cicada wing | 159 | Not hierarchical | | | 200 | Ø60 top and Ø100 base | 170 | 54 | |
| Dragonfly wings | - | Not hierarchical | | | 350 | Ø80 | 150 | 87 | |
| Dragonfly wings | 153 | Not hierarchical | | | 240 | 50-70 | 200 | 88 | |
| Dragonfly wings | - | Not hierarchical | | | Small: 189±67  Tall: 311±52 | Small: 37±6  Tall: 57±8 | - | 13 | |
| Dragonfly wings | - | Not hierarchical | | | 79.63-188.31 | Ø83.25-Ø195.08 | - | 89 | |

Table III Some bio-mimicked antibacterial surfaces and obtained outcomes.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Bio-inspiration** | **Fabrication process** | **Material** | **Surface type** | **Dimensions** | **Bactericidal effect** | **Reference** |
| Dragonfly wing | Hydrothermal etching | Titanium | Nanowires | Ø40.2±20 nm | *P. Aeruginosa:* 50% death.  S. Aureus: 20% death | 59 |
| Dragonfly wings | Reactive ion etching and CVD | Black silicon | Nanopillars | Ø20 nm-Ø80 nm  Spacing: 200 nm- 1800 nm | Effective against gram positive and gram-negative bacteria. | 88 |
| Dragonfly wings | Ion etching | Silicon | Nanopillars | Ø220 nm and 4 µm height | 83% of gram negative (*E. Coli*) and 86% of gram positive (*S. Aureus*) bacteria were killed | 90 |
| Cicada wing | Hydrothermal method | TiO2 | Nanowires | Ø100 nm  and  Ø10 µm-15 µm  Heights: 3 µm | *P Aeruginosa*: More than 50% death  *S. Aureus*: Less than 5% death | 91 |
| Cicada wing | Glancing angle sputter deposition | TiO2 on silicon substrate | Nanopillars | Ø33±7 nm  Peak-peak: 158±105 nm | E. coli: 50% death  S. Aureus: Successfully colonized. | 92 |
| Cicada wing | Nanoimprinting lithography | PMMA | Nanopillars | Ø150 nm, 400 nm height and 150 nm spacing | - | 93 |
| Cicada wing | Thermal oxidation | Ti6Al4V | Nanospikes | Ø20 nm | Enhance the bactericidal activity against *E. Coli* | 94 |
| Lotus leaf | Femtosecond laser | Titanium | Microbumps | Ø10 µm-Ø20 µm grains and 200 nm undulations | Lower adhesion of *P. aeruginosa* than polishes but increase of *S. Aureus*. | 37 |
| Lotus leaf | Femtosecond laser | Titanium | Microbumps | Ø10 µm-Ø20 µm grains and 200 nm undulations | *S. Aureus, S. Epidermidis* and *P. Maritimus* were able to attach to the surface. | 95 |
| Gecko skin | Template process | Epoxy resin | Nanoairs | 2 µm-4 µm length  2 µm height  500 nm spacing and base | *S. Mutan:* First 3 dayslower adhesion than original skin. After 7 days more than natural skin  P. Gingivalis: Higher adhesion than natural skin. | 53 |
| Shark skin | Photolithography + ion etching | PDMSe | Grooves | 2 µm width and spacing  3 µm height | Decrease of bacterial adhesion than smooth surface and avoid of biofilm formation. | 46 |

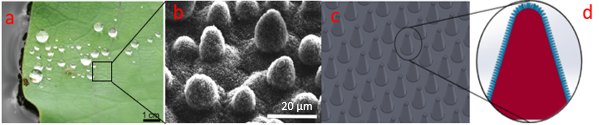


Figure 22 a) Natural lotus leaf. Adapted from84 b) Lotus leaf microstructure. Adapted from 27 c) Lotus leaf microstructure model (Proposed CAD model corresponding to SEM image) d) lotus leaf micropapillae (red colour) with nanobranches (blue colour) (Proposed CAD model corresponding to SEM image). Scale bar is 20µm.

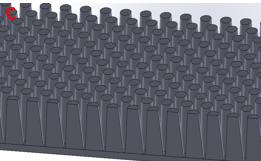
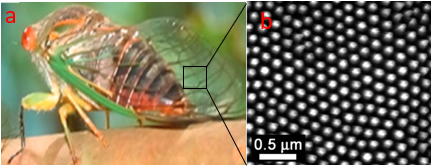


Figure 23 a) cicada. Adapted from 29 b) cicada wing SEM picture. Adapted from 87. c) cicada wing nanostructure model (Proposed CAD model corresponding to SEM image).

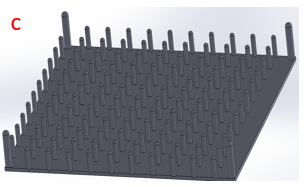
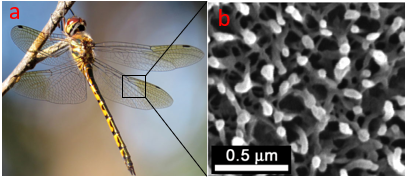


Figure 24 ) dragonfly insect. Adapted from 96 b) SEM image of a dragonfly wing Adapted from 87 c) Dragonfly wing model (Proposed CAD model corresponding to SEM image)

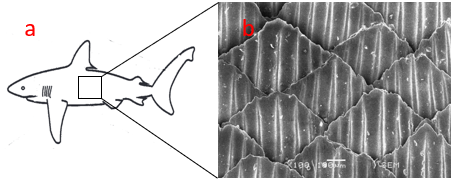


Figure 25 : a) shark animal. Adapted from 98 b) SEM of the shark skin microstructure Adapted from 45 c) model of the shark skin based on the Sharklet AFTM (Proposed CAD model corresponding to SEM image).

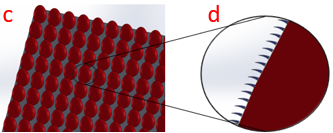


Figure 26 a) gecko animal b) SEM image of the dorsal part of the gecko animal. Adapted from 9 c) scales at the micro level creating the first level of the hierarchical structures (Proposed CAD model corresponding to SEM image) d) cross-section view of the scales (red colour) and the nanohairs (blue colour) creating the second level of the hierarchical structure (Proposed CAD model corresponding to SEM image).

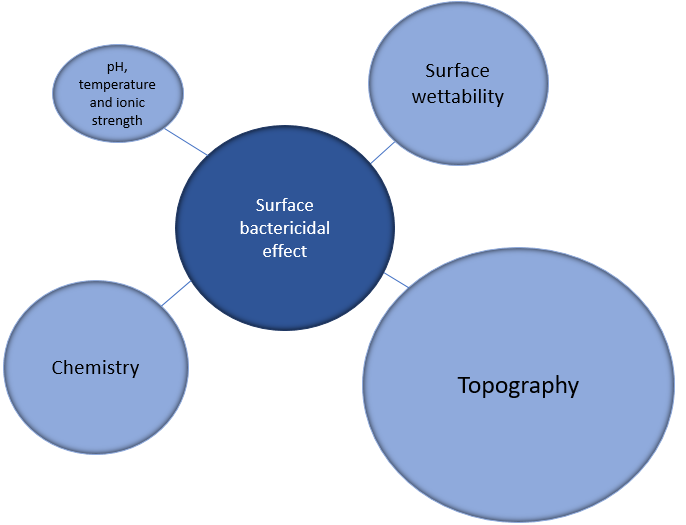


Figure 27: Illustration of the bactericidal effect and its root causes.

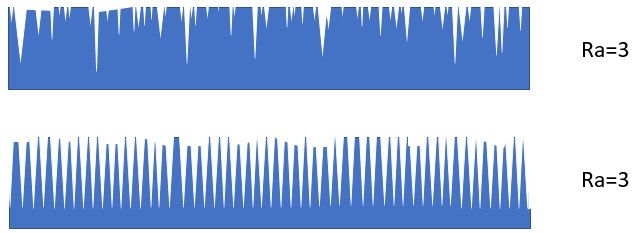


Figure 28 Same surface Ra but the morphology of this is not the same.

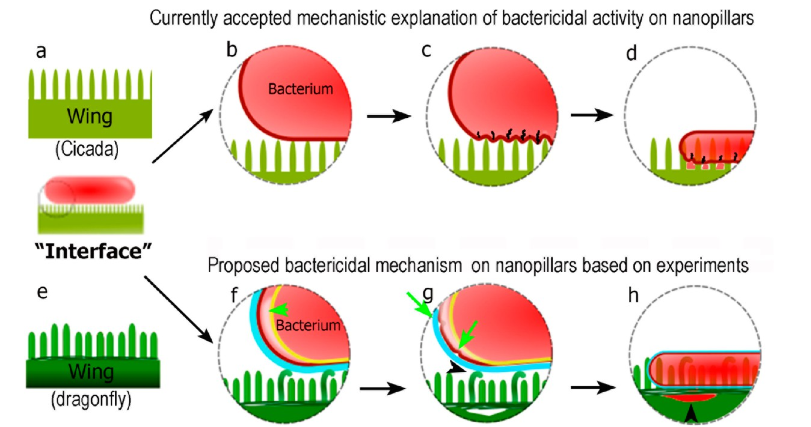


Figure 29 Representation of the bactericidal mechanisms of the nanopillars. a)-d) currently accepted mechanism between the interaction of bacteria-nanopillars. e)-h) proposed mechanism by Bandara *et al* .13. a) Cicada wing nanostructure with all pillar at the same height. b) bacterium approaching the nanostructure. c) bacterial membrane starts rupturing between the pillar like structures due to stretching. d) The bacteria get ruptured and the cytoplasm starts leaking leading to bacterial death. e) dragonfly wing illustration with variable lengths pillars. f) The approaching bacterium bends the taller pillars, but it doesn’t puncture the membrane. g) after adhesive forces are applied into the bacterial surface, the two membranes (EPS in blue and outer membrane in red) start separating. h) finally, the bacterium dies on the nanopillars and the cytosol leaks out. Adapted from 13.

Table V Bactericidal efficacy of different nanoparticles

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Nanoparticle | Dosses | Bacterial response | Manufacturing process | References |
| 3 sizes of Ag | 0.01 M | S. Mutans reduction. Bactericidal response depends on the size. | Gallic acid in an aqueous chemical reduction method | 138 |
| Ag | 4.26% using EDS | Remarkable antibacterial effect against S. Aureus and E. Coli | Silanization method | 139 |
| Ti nanotubes + Ag | 0.5 M, 1 M, 1.5 M and 2 M | Significant reduction of the osteoblast cells. | Immersion in a silver nitrate solution | 140 |
| Ag+ + hydroxyapatite | 296 mg/ml | More than 99% of S. Aureus and E. Coli were killed after 24 h | Dipping | 141 |
| Ag | 25-100 mg/l | Conclude 3 step process of P. Aeruginosa bacterial wall rupturing | - | 133 |
| Ag and ZnO | 10 mM | Small reduction of B. Subtilis bacteria reproduction | - | 142 |

Table VI: Antibacterial mechanism for antibacterial metals, their characteristics, and potential applications

|  |  |  |  |
| --- | --- | --- | --- |
| **Antibacterial mechanism** | **Corresponding antibacterial material** | **Characteristics** | **Prospective applications** |
| Slow release metal ion sterilisation | Copper, silver, metal ion phosphate antibacterial materials, etc. | High chemical activity provides long term and efficient slow release antibacterial materia | Widely used in medical applications, stainless steel, water treatment. Prevent bask in liquid coatings and fabrics. But these materials tarnish easily and are expansive, which limits their applications |
| Slow release metal ion sterilisation and photocatalytic sterilisation | Hydroxyapatite, Ag-carrying phosphate antibacterial materials, etc. | Phosphoric acid double salt has a strong adsorption function, large specific surface area, nontoxic, stable chemical properties; good combination of efficiency and lasting slowrelease performance |  |
| Slow release metal ion sterilization, photo-catalytic sterilization and reactive oxygen species antibacterial mechanism | ZnO materials, TiO2 materials | Stable chemical properties, under UV irradiation show broad spectrum antimicrobial properties, good pH stability, nontoxic, abundant raw material sources, low cost. | Used in fiber, plastic, ceramic, coating, biomedical and other fields |

Table VII: Antimicrobial activity of metal oxide nanoparticles

|  |  |  |
| --- | --- | --- |
| **Metal oxide NPs** | **Test organism** | **Antimicrobial action** |
| Aluminium oxide (Al2O3) NPs | Escherichia coli | Growth inhibition of Escherichia coli |
| Antimony trioxide (Sb2O3) NPs | Escherichia coli, Bacillus subtilis and Staphylococcus aureus | Toxic to all the three microbes |
| Bismuth oxide (Bi2O3) NPs | Pseudomonas aeruginosa, Acinetobacter baumannii and Escherichia coli | No effect against all tested microbes |
| Calcium oxide (CaO) NPs | Lactobacillus plantarum | Higher bactericidal activity |
| Cerium oxide (CeO) NPs | Escherichia coli, Shewanella oneidensis and Bacillus subtilis | No effect on Shewanella oneidensis |
| Cobalt oxide (Co3O4) NPs | Staphylococcus aureus and Escherichia coli | Showed antimicrobial activity on tested bacteria |
| Copper oxide (CuO) NPs | MRSA, Staphylococcus epidermis, Pseudomonas aeruginosa, Proteus sp. Staphylococcus aureus, Bacillus subtilis, Escherichia coli; fish pathogens: Aeromonas hydrophila, Pseudomonas fluorescens, Flavobacterium sp. and Branchiophilum sp | Active against all the tested microbes |
| Magnetite (Fe3O4) NPs | Escherichia coli | Concentration-dependent bacteriostatic action |
| Iron oxide (FeO) NPs | Staphylococcus aureus, Shigella flexneri, Escherichia coli, Bacillus licheniformis, Bacillus subtilis, Brevibacillus brevis, Vibrio cholerae, Pseudomonas aeruginosa, Staphylococcus aureus and Staphylococcus epidermis | Moderate antibacterial activity against 6 Gram-positive and 2 Gram-negative bacteria |
| Magnesium oxide (MgO) nanowires | Escherichia coli and Bacillus spp. | Lower bacteriostatic activity |
| Titanium dioxide (TiO2) NPs | MRSA | Exhibited antimicrobial effect on tested isolates |
| Zinc oxide (ZnO) NPs | MSSA, MRSA and MRSE, Streptococcus agalactiae, Staphylococcus aureus, Escherichia coli, Bacillus subtilis, Salmonella paratyphi, Staphylococcus aureus, Pseudomonas aeruginosa, Mycobacterium smegmatis, Mycobacterium bovis, Klebsiella pneumoniae, Enterobacter aerogenes, Candida albicans, Malassezia pachydermatis, Bacillus megaterium, Bacillus pumilus and Bacillus cereus | Active on tested microbes |
| Zinc/iron oxide composite NPs | Escherichia coli and Staphylococcus aureus | Exhibited greater antibacterial activity with higher Zn/Fe weight ratio |
| ZnO-loaded PA6 nanocomposite | Staphylococcus aureus and Klebsiella pneumoniae | Dose-dependent antibacterial action |
| Nanosilver-decorated TiO2 nanofibres | Staphylococcus aureus and Escherichia coli | Increased antimicrobial effect |
| Hybrid CH-α-Fe2O3 nanocomposite | Staphylococcus aureus and Escherichia coli | Improved antibacterial activity |
| Zinc-doped CuO nanocomposite | Escherichia coli, Staphylococcus aureus and MRSA | Remarkable biocidal activity |
| PEI-capped ZnO NPs | Escherichia coli | Exhibited better antibacterial activity |
| Chitosan-based ZnO NPs | Candida albicans, Micrococcus luteus and Staphylococcus aureus | Showed biofilm inhibition against Micrococcus luteus and Staphylococcus aureus |
| Carvone functionalized iron oxide | Staphylococcus aureus and Escherichia coli | Inhibited colonization and biofilm formation |
| Silver-decorated titanium dioxide (TiO2 : Ag) NPs | MRSA and Candida sp. | Conferred antimicrobial effect on tested microbes |
| Graphene oxide modified ZnO NPs | Escherichia coli, Bacillus subtilis, Salmonella typhimurium and Escherichia faecalis | Excellent antibacterial activity |
| **NPs: nanoparticles; MRSA: methicillin-resistant** Staphylococcus aureus**; MRSE: methicillin-resistant** Staphylococcus epidermidis**; MSSA: methicillin-sensitive** Staphylococcus aureus**; PEI: polyethyleneimine.** | | |

Table VIII: State of the art of bactericidal treatments based on silver ion implantation:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Ion | Substrate | Plasma ion source | Bias/Acceleration voltage (kV) | Dose  ions/cm2 | Bacteria tested  *In vivo* studies | Reference |
| Ag | Ti | ECR | 2 | 1.5·1016 | S. aureus | 154 |
| Ag | Ti | Cathodic arc | 30 | - | E. coli, S. aureus | 155 |
| Ag | Ti | Cathodic arc | 20 | - | *In vivo* positive response | 153 |
| Ag | Ti | MEVVA | 40 | 1016 | S. aureus | 156 |
| Ag | Ti | Cathodic arc | 15 | - | F. nucleatum, S. aureus | 151 |
| Ag | TiO2-Ti | MEVVA | 70 | 1017 – 2·1018 | S. aureus | 157 |
| Ag | 316LVM | Cathodic arc | 30 | - | E. coli, P. aeruginosa, S. aureus, S. epidermis | 147 |
| Ag | TiO2 | MEVVA | 40 | (0,5-10)·1016 | E. coli | 158 |
| Ag | Ti | Cathodic arc | 30 | - | In vivo positive response  Osseoconductive treatment | 159 |
| Ag | TiO2-Ti | Cathodic arc | 0,5-1 | - | P. gingivalis, A. actinomycetemcomitans.  In vivo positive response | 148 |
| Ag | CrN-316L | Kaufman ion source | 100 | 5·1016-1017 | E. coli, S. aureus | 160 |
| Ag | TiO2-Ti | MEVVA | 65 | (1-20)·1017 | S. aureus | 161 |
| Ag | AISI 420 | MEVVA | 50 | 1017 | E. coli | 162 |
| Ag | Ti | Cathodic arc | 15 | - | S. mutans. P. gingivalis, C. albicans | 149 |
| Ag | Ti | ---- | 15 | 1016 | A. actinomycetum, F. nucleatum, C. rectus, P. micros, B. forsythus | 150 |
| Ag | Ti | Cathodic arc | 30 | - | E. coli, S. aureus | 163 |
| Ag | 317L, TiN-317L | MEVVA | 70 | 5·1016 – 5·1018 | S. aureus | 164 |
| Ag | Pyrolytic carbon | MEVVA | 70 | 5·1014- 5·1018 | E. coli, S. aureus | 165 |
| Ag/Zn, Ag+Zn | Ti | Cathodic arc | 30 | - | E. coli, S. aureus.  In vivo positive response | 166 |
| Ag, Ag+Mg | Ti | Cathodic arc | 30-40 | - | E. coli | 167 |
| Ag/Ca, Ag+Ca | Ti alloy | MEVVA | 50 | 1017 | E. coli, S. aureus | 168 |
| Ag/Zn, Ag+Zn | Ti | Cathodic arc | 30 | - | E. coli, S. aureus  In vivo positive response | 152 |
| Ag+Cu | AISI 420 | MEVVA | 50 | 2·1017 | S. aureus, A. niger | 169 |
| Ag/Cu | Ti6Al4V | CHORDIS | 2-20 | 1015-1017 | E. coli, S. aureus | 170 |
| Ag/Cu | Polyethylene | Cathodic arc | 5 | - | E. coli | 171 |
| Ag/Cu | 317L, Ti, TiAlNb | MEVVA | 80 | 1017 | S. aureus | 172 |

Figure 30: Overview of the manufacturing techniques classification.

Table IX Classification of additive type surface modification techniques 36,211

|  |  |  |
| --- | --- | --- |
| **Additive processing** | | |
| **Chemical processes** | Chemical conversion coating | Patterned chromating |
| Patterned phosphating |
| Chemical deposition coatings | Chemical vapour deposition (CVD) |
| Patterned autocatalytic plating |
| Anodising |
| \*Electro-deposition |
| Sol-gel |
| Patterned precipitation coating |
| **Physical deposition** | Inkjet |
| Patterned curing |
| Physical vapour deposition (PVD) |
| Painting |
| \*Deposition of micro- or nanoparticles |
| \*Self-assembling in polycrystalline films |
| Vacuum casting |

\*Considered as an Ultra Precision manufacturing technique.

Table X Additive manufacturing processes employed to suppress the bacterial adhesion

|  |  |  |  |
| --- | --- | --- | --- |
| **Additive process** | **Material employed** | **Bacterial response** | **Reference** |
| Anodization | Grade 2 Ti and Ti6Al4V | Successful bactericidal activity of the anodized samples | 129 |
| Nanoimprint lithography | PMMA | 50% decrease of E. Coli bacteria compared to polished ones | 227 |
| Electrodeposition | Au nanoparticles | All structures Au nanoparticles exhibit great bactericidal activity against *S. Aureus* | 228 |
| Physical vapour deposition | Titanium coated with copolymers | Decrease of the *S. Aureus* bacteria. | 229 |
| Spraying deposition | Titanium anodized substrate coated with polylactide. | 0.5% of PLA concentration showed the best inhibition rate to *S. Aureus*. | 230 |
| Lyophilization method | Titanium nanotubes loaded with gentamicin | Reduction of s. Aureus and enhance the osteoblast | 231 |
| Physical vapour deposition | Grade 2 Ti with silver coating | Reduce the bacterial adhesion of *S. Epidermidis* and *K. Pneumoniae*. | 221 |
| Chemical vapour deposition | Silicone elastomer | Decrease of S. Aureus bacteria compare with uncoated sample | 232 |
| Ag and Cu Ion implantation | 317L, Pure Ti, TiAlNb | Improve the antibacterial properties of the substrates | 170,172 |

Table XI Classification of the removal of material surface modification techniques 36,211 by subtractive routes

|  |  |  |
| --- | --- | --- |
| \***Removing material** | | |
| **Beam based methods** | Laser methods | Laser texturing (LT) |
| Masked excimer laser |
| Laser honing |
| Focused ion beam |
| CNC focused laser |
| Femtosecond laser |
| Electrical discharge machining (EDM) | Electrical discharge texturing (EDT) |
| Micro EDM |
| Ion beam texturing |
| **Chemical etching** | Masking methods | Chemical texturing |
| Electrochemical texturing |
| Non-masking methods | Self-assembling |
| Maskless laser assisted etching |
| Maskless electrochemical texturing |
| Anisotropic etching |
| **Mechanical** | CNC ultrasonic machining |
| Mechanical honing |
| Precision Grinding |
| Free abrasive machining |
| Microcutting |
| Patterned erosion |

.

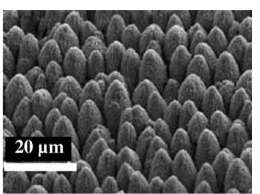


Figure 31 Femtosecond laser processed cone type structure on titanium material 243.

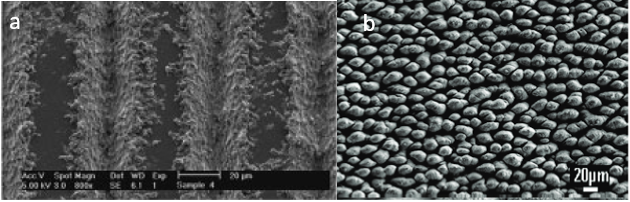


Figure 32 a) Ti6Al4V sample with 50 µm separation tracks. Adapted from 246 and b) laser processed titanium sample inspired from a lotus leaf. Adapted from 37.

Table XII Subtractive manufacturing processes employed to create bactericidal surfaces

|  |  |  |  |
| --- | --- | --- | --- |
| **Subtractive process** | **Material employed** | **Bacterial response** | **Reference** |
| Femtosecond laser | Ti6Al4V | Similar bactericidal (*S. Aureus*) response between nanopillars and LIPSS. | 119 |
| Femtosecond laser | Ti6Al4V | Colonisation of *S. Aureus* on all the laser treated surfaces but rejection of *P. Aeruginosa* and *S. Mutans* on nanopillar like structure. | 245 |
| Nanosecond laser | Ti6Al4V | Biofilm formation of *E. Coli* and *S. Aureus* on non-treated surface but bacterial attachment was not avoided. | 253 |
| CW laser | Ti6Al4V, CoCrMo and CpTi (Grade 2) | The most bactericidal surface was observed on the CpTi against *S. Aureus* which exhibits the lowest CA (31.9°) | 120 |
| Machining vs Sand blasting + acid etching | Pure Ti | Machined samples showed better bactericidal activity *S. Sanguinis* than acid treated ones. | 254 |
| Polishing vs grit blasting vs plasma sprayed vs satin | Ti6Al4V | Polished surface showed lowest S. epidermidis adhesion continued by plasma spraying, grit-blasting and sating. | 100 |
| Chemical oxidation | Grade 2 Ti | Avoid bacterial adhesion of *S. Aureus* and *E. coli* compared to smooth one. | 255 |
| Plasma glow discharge | PVC | Significant decrease of the *P. Aeruginosa* bacteria. | 256 |
| Plasma treatment | Polymeric suture materials | Reduction of E.Coli bacteria depends on the available contact area. | 257 |

Table XIII Classification of the re-structuring surface modification techniques 36,211.

|  |  |  |
| --- | --- | --- |
| **Re-structuring** | | |
| **Mechanical** | Shot blasting |  |
| Embossing | Vibrorolling |
| Patterned embossing tools |
| Lithography |
| Wrinkling\* |
| Photolithography |
| **Chemical** | Molecular migration |
| UV contraction |

\*Considered as an Ultra Precision manufacturing technique.

Table XIV Impact of the surface properties of different manufacturing techniques.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Technique** | **Surface property impact** | | | | **Reference** |
| **Chemistry** | **Wettability** | **Topography** | **Other** |
| Femtosecond laser | Medium | Strong | Strong (nanoscale, microscale) | No surface damage | 37,119,245,260 |
| Nanosecond laser | Medium | Strong | Medium (microscale) | Surface damage | 253,261 |
| Ion Implantation | Strong | Weak | Weak | - | 171,172 |
| Anodization | Weak | Weak | Weak | - | 129 |
| Chemical oxidation | Strong | Strong | Strong (nanoscale) | - | 255 |
| PVD | Strong | - | Medium (microscale) | - | 221,229 |
| CVD | Strong | Medium | Medium (microscale) | - | 232 |

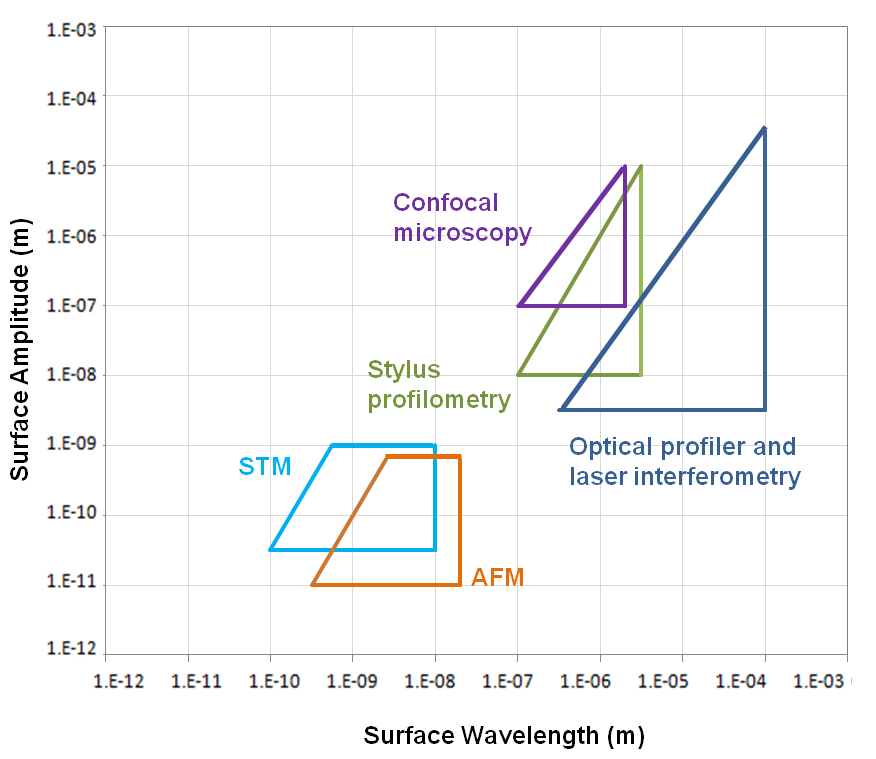


Figure 33: Stedman diagram: Typical resolutions of some common metrology used to asseses surface modified fabrication methods. Adapted from 264.

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