Nanofabrication of mechano-bactericidal surfaces

The adaptation of bacteria to survive in the presence of antibiotics and their ability to form biofilms on conventional antibacterial surfaces has led to an increase in persistent infections caused by resistant strains of bacteria. This presents a worldwide health epidemic that can only be mitigated through the search for a new generation of biomaterials. The search for alternatives to the standard methods of preventing bacterial adhesion and biofilm formation on biotic and abiotic surfaces alike has led to the use of biomimetics to reinvent, through nanofabrication methods, surfaces whereby the nanostructured topography is directly responsible for bacterial inactivation through mechanical means. Biomimicry or ‘mimicking nature’ is a method currently used to increase the biocompatibility of materials using surface modifications on the micro- and nanoscales. Our work has utilised the nanopillared surface of insect wings to inspire the design of mechanically biocidal surfaces, using a biomimetic approach, and realised through advanced nanofabrication techniques.

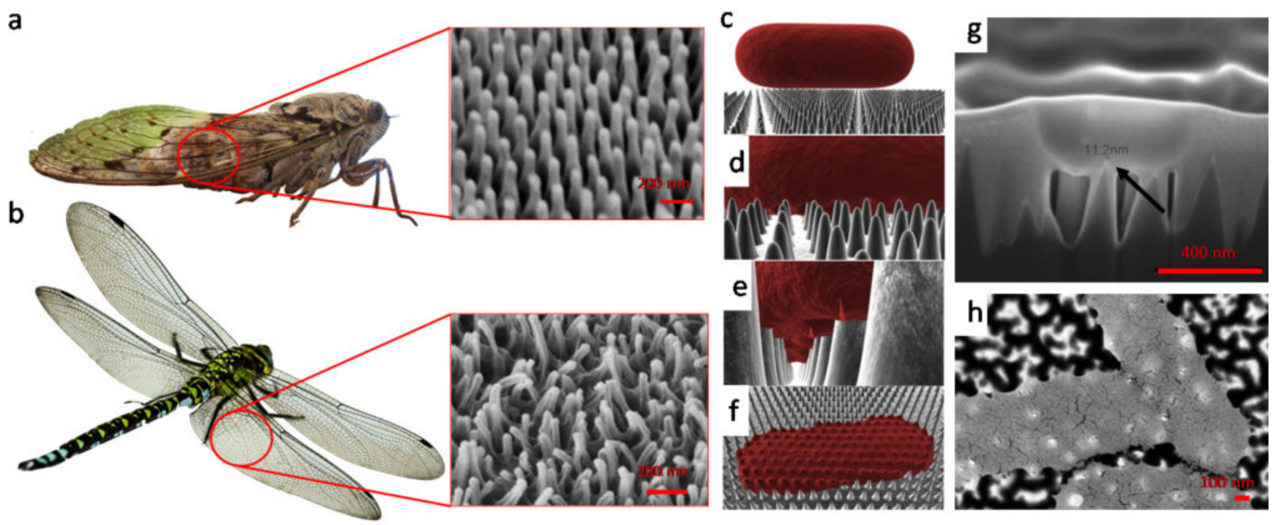

Fig. 1. Bio-inspired synthetic nanopillared mechanically biocidal surfaces. Photographs of (a) cicada and (b) dragonfly and corresponding high-magnification SEM micrographs of the nanopillared surface. (c-f) Schematic of the process of mechanical inactivation of a bacterial cell upon adsorption onto a nanopillared substrata. (g) Focused-Ion-Beam milling of the interface of a bacterial cell and nanopillared substrata, showing indentation of the membrane. (h) top-view SEM micrographs of bacterial cells which have been ruptured on ‘black silicon’ substrata.

Black silicon surfaces consisting of a needle-like array of nano-protrusions were the first reported ‘biomimetic’ surfaces to exhibit mechano-bactericidal activity together with a capability for large-area industrial upscaling in fabrication. The plasma etching of silicon substrata uses nonhazardous and process-stable gases, based on a competing fluorine and oxygen chemistry to etch surface structures through physical ion bombardment and chemical surface reactions. It is a straight forward method of achieving high-aspect-ratio anisotropic structures on silicon substrates which have been demonstrated to be capable of placing enough physico-mechanical stress on the bacterial cell membrane to lead to cell deformation and subsequent cell death of ~99 % of contacting bacteria.

For the precise patterning of metallic surfaces over large areas, hydrothermal treatments and anodic oxidation of titanium have been determined as single-step, simple and affordable, yet effective ‘template-free’ techniques, and have been widely used to create biocompatible implant materials. The hydrothermal treatment of titanium involves the immersion of either TiO_2 powders or titanium metal in an alkaline solution at elevated temperatures in a sealed chamber. This method can achieve a variety of surface features, including needles, wires, sheets and tubes/rods which have been compared to the surface of dragonfly wings.

The above nanofabrication methods represent conventional ‘top-down’ techniques which are capable of scalable fabrication of large area mechano-bactericidal surface patterns. Recently, we have developed a novel ‘bottom up’ fabrication technique which exploits the interactions between molecules and particles for the self-assembly of 2D or 3D nanostructures. Self-assembled palmitic and stearic fatty acid crystals (the two main lipid components of the epicuticle of insect wings) on highly ordered pyrolytic graphite produced micro-crystallite interfaces with effective mechano-bactericidal activity. The simplicity of the production of these nanostructured surfaces suggests the possibility of effectively applying these fabrication techniques to manufacture bactericidal materials and nanocoatings for use in varied biomedical and industrial applications.

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