Ultrananocrystalline diamond (UNCD™) coating for new-generation implantable medical devices/prostheses

openaccessgovernment.org/article/ultrananocrystalline-diamond-coating-for-new-generation-implantable-medical-devices-prostheses/170895

1 December 2023

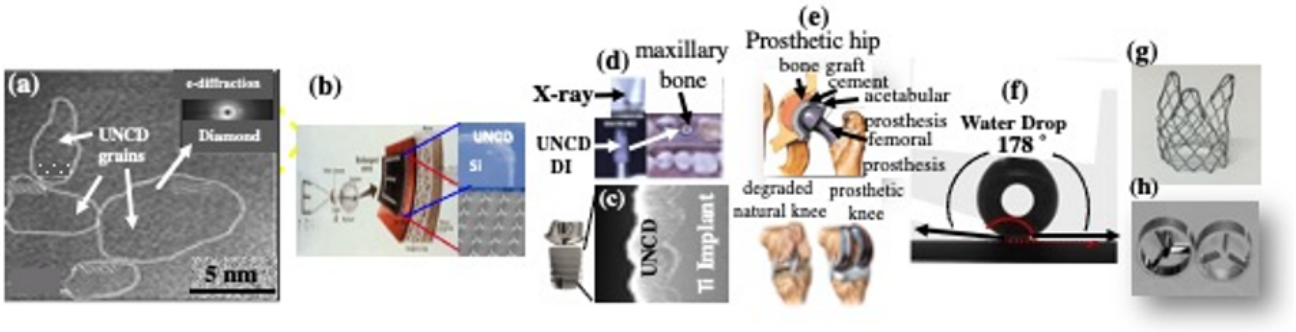

Figure 1. (a) High-resolution transmission electron microscopy image of UNCD™ coating, showing 3-5 nm grains; (b) Schematic of Si microchip (artificial retina)-left/cross-section scanning electron microscopy (SEM-top right) image of UNCD-encapsulated microchip and electrodes (bottom) made of Si tips coated with unique electrically conductive N atoms-doped N-UNCD coating. Injecting electrons in ganglion cells, transferring to the brain to produce an image; (c) Cross-section SEM image of UNCD-coated DI; (d) X-ray image of UNCD- coated DI (upper left) and UNCD-coated DI in maxillary bone of one of 51 patients implanted with UNCD-coated DI in clinical trials (2018 to present); (e) Schematics of artificial hip (top)/knee (bottom) to be coated with UNCD™; (f) Water drop contact angle (178˚) on CF4 plasma processed UNCD™ surface, showing highest super-hydrophobicity of any known biomaterial, inhibiting blood cells adhesion on stent's surface (Fig. 1(g))/heart valve's surface (Fig. 1 (h)), eliminating thrombus formation. (5)

In this materials science piece, Orlando Auciello, describes the development of a unique multifunctional/best biocompatible ultrananocrystalline diamond (UNCDTM) coating for new-generation implantable medical devices and prostheses

Materials' surfaces of vital medical devices, such as silicon (Si) microchip (artificial retina) implanted on human retina, restoring partial vision to people blinded by genetically induced photoreceptors degeneration, and metallic dental implants, are attacked chemically by eyes' fluids or oral fluids respectively.

Metallic stents/artificial heart valves, inside human blood vessels, activate blood enzymes, inducing coagulation, and fibrinolytic, leading to thrombus formation (i.e., blood clot in blood vessels, obstructing blood flow or loosed clot getting stuck in arteries/veins' walls, causing life-threatening stroke/heart attack.

Polytetrafluoroethylene (PTFE) and Diamond-like Coating (DLC) are investigated to protect metallic implants/ surfaces. However, PTFE exhibits nonuniformity/instability/poor adhesion on metals, resulting in delamination. DLC coating provides lubricity/biocompatibility but degrades in fluids.

The problems described above are solved by using a transformational ultrananocrystalline diamond (UNCD™) coating, developed by Auciello et al., grown by microwave plasma and hot filament chemical vapor deposition, using patented Ar/CH_4 gases, with CH_4 cracked into C atoms, linking chemically to each other, with diamond-type bonds, on substrates' surfaces. The (UNCDTM) coating exhibits unique combined physical/chemical/mechanical/electrical /biological properties, the latter promoted by UNCDTM exhibiting the best biocompatibility because it is made of C-atoms (element of life in human DNA/cells/molecules).

Materials problems for key implantable medical devices/prostheses

Key materials problems in critical medical devices/prostheses, implantable in humans, replacing degraded natural body parts to improve quality of life, include:

- Si-microchip implantable on human retina, receiving images from CCD camera outside the eye, processing images/injecting electrons in retina's ganglion cells, which axons (optical nerve) transmit electronic information to brain's cells, restoring partial vision to people blinded by gene-induced death of photoreceptors (retinitis pigmentosa). The Argus II device, developed in a 10-year R&D project, returned partial vision to blind people in the U.S./EU markets since 2011 (Ch. 2/Ref. [(1)]). However, the eye's fluids induce chemical corrosion, destroying the Si chip and thus requiring the current chip setting in a box outside the eye.
- Dental implants (DI), replacing destroyed natural teeth, are made of metals (~ 90 % made of Ti-6Al-4V alloys). The Ti-alloy surface is oxidized by atmospheric oxygen (O). Oral fluids etch the oxide layer, ejecting TiO2 particles, injecting into mouth tissue, killing cells/inducing inflammation. About 15% of commercial Ti-alloys DIs fail worldwide in four to five years, requiring replacement, involving pain/extra cost to people (Ch. 5/Ref. [(1)]).
- Artificial hips/knees/elbows/other prostheses, made of stainless steel or Ti-alloy, chemically attacked by body fluids, need replacement earlier than desirable (Ch. 5/Ref. [(1)]).
- Metallic stents/artificial heart valves contacting blood, release enzymes, inducing coagulation/fibrinolytic/kinin and thrombus formation (i.e., a blood clot inside blood vessel, obstructing blood flow, and/or clot breaking loose, sticking in blood vessels, potentially inducing stroke/heart attack.

Polytetrafluoroethylene (PTFE)/Diamond-like Coating (DLC) coatings are investigated to improve the mechanical/chemical performance of the metals' surfaces of prostheses. However, PTFE exhibits nonuniformity/instability/poor adhesion on metals. DLC coating

exhibits a wide range of C atomic bonds, potentially responsible for high stress/coating degradation in fluids (see review of metal prostheses problems [2]).

Materials problems described above are solved using a UNCD™ coating, described in Section 2.

Materials science/technology development for transformational low-cost/best biocompatible UNCD™ coating

The transformational UNCD™ coating, developed (Ch. 1 in [1], [3]) and patented [4] by Auciello et al., is grown by microwave plasma and hot filament chemical vapor deposition, using a patented Ar/CH_4 gas chemistry flown into an air evacuated system. Where CH_4 molecules crack, releasing C atoms, linking to each other, with diamond-type C atoms bonds, on substrate surfaces, producing UNCD™ films (3-5 nm grains (Fig. 1 (a)-smallest of polycrystalline diamond coatings).

UNCD™ films exhibit unique combined physical/chemical/mechanical/ electrical/biological properties, namely: 1) Hardness (98 GPa)/Young modulus (1000 GPs), like diamond gem; 2) lowest friction coefficient (≤ 0.04) than other materials (≥ 0.5) used in prostheses; 3) resistant to corrosion by eye's fluid, oral fluid, joint fluids; 4) best biocompatibility (because made of C-atoms-element of life in human DNA/cells/molecules); 5) super-hydrophobic surface, eliminating blood cell adhesion in cardiovascular stent and heart valves.

The transformational UNCD™ coating enables new generations of superior implantable medical devices/prostheses, improving people's quality of life worldwide.

References

1. Auciello O (editor/author), "Ultrananocrystalline Diamond Coatings for New Generation High-Tech/Medical Devices (book), Cambridge (2022).
2. Coronel-Meneses D et al., Bioeng. Biotechnol. Sec. Biomaterials, 11 (2023.) https://doi.org/10.3389/fbioe.2023.1173260
3. Auciello O, Sumant A V, Diamond Related Materials 19 (2010), 699.
4. Naguib N, Auciello O et al., U.S. Patent #7,128,889 (2006). 5. Zeng H, Jarvik R et al., Surf.Coat.Technol. 302 (2016), 420.

Please Note: This is a Commercial Profile